Analysis of soil chemical residues and other soil factors associated with past human activity

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[77, 000 words]

ABSTRACT

The activities of past human communities, by and large, generate organic deposits, components of which, over time, remain in the soil as persistent and measurable chemical residues. It is suggested that these residues derive, for the most part, from human and livestock excreta, wood ash and other domestic waste. The residues remain associated with the foci of settlements long after other evidence of occupation has disappeared.

Samples of top soil from identified (or conjectured) abandoned settlements, dating from the Roman to the medieval period, were taken from twelve locations (19 assessments) in the British Isles. These samples were analysed for a range of heavy metals (Cd, Co, Cr, Cu, Pb, Mn, Ni & Zn) using single element atomic absorption spectroscopy. Soil pH and magnetic susceptibility, and the organic carbon and phosphorus content of the samples were also evaluated. The distribution over the sampled areas of individual and combined soil qualities were mapped.

It was shown that, of the heavy metals tested for in the soils, lead, and to a lesser extent, zinc, copper and cadmium were positively site-indicative and that nickel, cobalt and chromium, through a process of competitive accumulation (dilution) were negatively site-indicative. Phosphorus, organic carbon (as measured by loss on ignition), and magnetic susceptibility also proved to be strong positive indicators, but none of these as consistently as lead. The identified positive and negative groupings were, on the whole, consistent across all sites. It was also shown that multi-factor evaluation of the anthropogenic components of soils derived from past settlements, when subject to multivariate statistical analysis, provided some insight into the nature of past activities (*type-signatures*) and when these activities occurred (*time-signatures*).

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AUTHOR'S DECLARATION

I declare that the work in this dissertation was carried out in accordance with the Regulations of the University of Bristol. The work is original except where indicated by special reference in the text and no part of the dissertation has be submitted for any other degree.

Any views expressed in the discussion are those of the author and in no way represent those of the University of Bristol.

The dissertation has not been presented to any other University for examination either in the United Kingdom or overseas.

SIGNED: Andrea Jackson DATE: 13/09/01

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INTRODUCTION

Over the years, archaeological field work has incorporated a range of multi-disciplinary techniques including environmental assessment and geo-physical prospecting. Analysis of soils for chemical changes associated with human activity or occupation has also become an accepted methodology but, because reliable results have often depended upon time consuming laboratory work, it was not widely practised. The more recent adoption of improved laboratory technology has enabled faster processing but has not always improved our comprehension of the underlying principles. It remains the case that the effects of past human activity on the chemistry of the soil are profound and complex; that soil analysis as an archaeological tool warrants more attention and greater emphasis; and that the theory and application of this methodology has been neglected at the cost of useful information extractable from the archaeological record.

The research contained in this thesis evolved from a series of projects undertaken by third year biology students at the University of Bristol between 1995 and 1998. Under the supervision of Dr. Mike Martin, a botanist widely recognised for his work on environmental pollution (particularly heavy metals) and in co-operation with archaeologist Professor Mick Aston, students were encouraged to look for ancient traces of pollution within a particular landscape. This landscape comprised of the northern slopes of the Polden Hills and the peat moorland contained within the Somerset parish of Shapwick: the "Shapwick Project" being an eleven year study jointly managed by the University of Bristol and King Alfred's College, Winchester. The object of the project was to discover, by using a wide variety of archaeological techniques, the origins of the present village of Shapwick and to find evidence of settlement prior to nucleation in the tenth century. In what was essentially an aceramic culture in which timber, wattle, daub, leather and cloth were the main materials of everyday life, the location of dispersed early medieval homesteads by conventional archaeological methods was all but impossible. It was conjectured, however, that sites of such ancient activity might have left evidence, if only in the form of contaminated soils. The results of these student projects proved to be most interesting, in one case revealing a ditch system and in another an area of soil heavily contaminated with lead overlying what later excavation proved to be a small Roman building. In 1996, as part of an MA project, the author undertook the study of a field to the east of Shapwick village which had been, until the fourteenth century, the

location of the medieval church. Fieldwalking and earthwork surveys indicated a complex pattern of previous habitation. Soil was removed from the field primarily for the purposes of heavy metal analysis but it became evident that there was also a clear association of darker soils with areas of occupation. In an attempt to identify the cause of this darkening, loss on ignition measurements (an estimate of organic carbon) and magnetic susceptibility (evidence of burning) were added to the portfolio of tests, as was phosphorus and (at a later stage) soil pH. Also, as part of the MA Project, a medieval settlement in north Somerset was similarly tested. Both sites gave very similar results; a close association of certain heavy metals and phosphorus with the focus of habitation and some indication of the alignment of buried features (Jackson, 1997).

The following research is a continuation and expansion of this initial work and examines twelve separate sites which include locations in Ireland, Gwent, Gloucestershire, North Yorkshire, and Somerset. As alluded to above, much of the theory and methodology incorporated in this study stems from the application of pollution science and the emphasis throughout has been on heavy metals. It would, however, be inappropriate to describe what follows as an examination of past human pollution as the term is associated with a concept of harmful or hazardous contamination. It would be more accurate to define it as a study of persistent changes in soil chemistry attributable to human activity. Indeed as just another aspect of the archaeological record. The principles and theory underlying soil analysis allow the application of the technique by archaeologists both as a means of prospection and potentially as a diagnostic tool. The object of this piece of research is to demonstrate that a wider use of soil analysis, particularly for heavy metals, will increase our knowledge of sites of human occupation and shed some light on the activities practised there.

In Part 1 of this thesis consideration is given to soil analysis as an archaeological technique and describes the proposed research. Part 2 examines human processes and activities that generate anthropogenic deposits, then considers the residues that survive over time and how these are recognised. Part 3 describes methodology and practice. Part 4 contains the details of the twelve sites (19 assessments) undertaken. Part 5 presents and comments upon the data collected. Part 6 is given over to a general discussion of the heavy metal results and how they relate to the (limited) contemporary work published elsewhere. Finally, in Part 7, conclusions are drawn on how human activity affects soil and the archaeological importance of recognising these effects are discussed.

Part One: Soil Analysis

INTRODUCTION

This part of the dissertation briefly considers soil analysis as an archaeological technique and the principles that underlie it. The method of soil analysis used and the previous work that led to its adoption are then discussed. A description of the proposed research is then presented together with the hypotheses upon which the research is based.

1.1 SOIL ANALYSIS AS AN ARCHAEOLOGICAL TECHNIQUE

Relative changes in the qualitative properties of soils have been used by archaeologists as indicators of past human activity for many years. Measurements have been made of the electro-magnetic, mechanical and chemical nature of the soil to extract unique information from sites under investigation.

As for the **electro-magnetic properties of the soil**, many of the modern geophysical methods provide a means of searching for discontinuities in the soil profile or subterranean anomalies recognisable, for example, by variations in electrical conductivity (Resistivity); as relative disturbances in the natural magnetic field (Magnetometry & Gradiometry); or in the effect of the magnetic properties of these anomalies on the sensing equipment (Magnetic Susceptibility). Other techniques detect discontinuities or anomalies by interpreting the reflection of sonic or electromagnetic (Sonar, Ground Penetrating Radar, Metal Detectors) pulses. Resistivity meters were used by archaeologists as early as 1946 (Clark, 1996,12) and magnetometers by 1958 (Clark, 1996,16); the procedures being so cumbersome at first that few considered archaeological geo-physics as having much of a future. Advances in computing and micro-electronics in the 1970s and 1980s changed everything and these techniques have become an indispensable part of archaeological investigation.

Analyses of the **mechanical properties of the soil**, in particular the evaluation of the relative size and distribution of soil particles, were used by archaeologists in the 1930s to identify candidate profiles in fluvial deposits (Zeuner, 1932) and procedures on the much closer examination of soil micro-morphology were being described in the 1950s (Cornwall, 1958). Interest in particle size analysis as an adjunct to soil phosphorus evaluation has been evident over the years (e.g. Williams & Saunders, 1956; Davidson, 1973) but a more holistic approach to anthropogenic soils came from later work in the

Netherlands (Van de Westeringh, 1988). Conclusions were drawn on ancient agricultural practices through the collective evaluation of soil particle size, soil colour, soil acidity, soil phosphorus and soil carbon : nitrogen ratios. This work has been subsequently expanded upon, particularly by researchers at the University of Stirling (Dockrill *et al*, 1994; Simpson, 1997; Simpson & Bryant, 1998 ; and Simpson 1998).

The archaeological interpretation of the **chemical properties of the soil** has a longer history than any of the techniques described above; the association of soil phosphorus and ancient settlement sites recorded in the early part of the last century *(a full review of soil phosphorus analysis in archaeology can be found in Part 2)*. Indeed soil phosphorus analysis has dominated archaeological geo-chemistry for nearly eighty years. An interest in anthropogenic residues of metals dates from the 1950s and archaeological soil-metal analysis has reached new levels of sophistication in recent years. These latest developments are discussed in more detail below. The evolution of soil metal evaluation and of other soil residues are discussed more generally in Part 2. Recent work on chemical isotope ratios and persistent hydrocarbons will also be addressed below.

As this thesis is concerned primarily with the chemistry of soils that have been altered by the activities of humans, it would be well to start with a clear definition of the principles involved.

1.2 THE PRINCIPLES OF SOIL CHEMICAL ANALYSIS

The chemical constitution of soil, although complex and (even today) not fully understood, is essentially pre-determined by natural chemical and biological processes. Soils are, in most cases, biologically active and chemically dynamic. Where localised variation in the soil chemistry occurs and an explanation unconnected with human activity is not forthcoming, an anthropogenic cause must be sought. This may be recent additions of agricultural fertilisers, current cropping practices, modern pollution or the result of past, possibly very ancient, land use. In a search for the ancient sites of occupation or activity an archaeologist will need to know, therefore, what soil chemistry is relevant to the investigation, how to locate it, how to distinguish it from the "natural" background and, importantly, how to recognise ancient deposits among the modern. Essentially archaeological soil chemistry is about identifying persistent changes to native soil brought about by past human activities. These disturbances may be dilutions, depletions or, as is more often the case, the enhancement of certain chemical elements

associated with the site of occupation. It will be demonstrated that in suitable places it is possible to distinguish a pattern of disturbance of soil elements that is linked to such ancient past activities. The emphasis is on activity (such as domestic occupation, agriculture or industry) and not on precise features. The biggest problem that arises appears to be that any observed patterns in soil metal distribution cannot be attributed to any particular time period and without an appreciable amount of investigation certain disturbance patterns are unable to be associated with any specific habitation activities. It is unlikely that this survey method could be used in isolation; it is anticipated that this could be an additional technique to be used alongside other established methodologies such as fieldwork, aerial surveying and geophysical surveying. However the technique may be one way to discover archaeological sites where neither surface nor subsurface features exist.

1.3 THE ANALYTICAL PROCESS

As has been the case with geo-physics, the successful application of archaeological geo-chemistry has been hampered over the years by the cumbersome process of providing useful results. The whole history of archaeological soil phosphorus examination (see Part 2, section 2.6) has been the pursuit on one hand of rigorous (and sometimes hazardous) laboratory-based chemical extraction, and on the other of a quick and simple field test. The trade-off being between the long delays in obtaining the reliable results of the former or the inevitable inaccuracies of the latter. Both are frustrating and neither produce results that are directly comparable. Apart from loss on ignition evaluations of soil carbon, chemical analysis was the only means of assessing the elemental content of soils until the adoption of mass spectrometry.

In this dissertation, circumstances have dictated the use of a simple Atomic Absorption Spectrometer (AAS) for the analysis of soil metals. For phosphorus, a spectrophotometer was used (see Part 3, section 3.3). Other workers have been able to use a variety of more recently developed multi-element techniques. Entwistle (1994) used Inductively Coupled Plasma Mass Spectrometry (ICP-MS); Rimmington (1999) used Inductively Coupled Plasma Atomic Emission Spectrometry (ICP-AES) and Taylor (pers. com) is using X-ray Fluorescence Mass Spectrometry (XRF-MS). In these cases, phosphorus determination was not always straightforward (see Part 6). Both AAS and ICP techniques require a laborious digestion process before samples can be subjected to spectroscopy, whereas soils subjected to XRF, although requiring some preparation, avoid this.

Access to an Atomic Absorption Spectrometer in a pollution-research laboratory in the Biological Sciences Department of Bristol University, a laboratory in which work had already begun on the archaeological associations of soil residues, was a major incentive to undertake this research. Although the alternative of using multi-element ICP facilities elsewhere in the University or at the NERC Laboratory, Holloway College, was always a possibility, it was the pollution science approach which appealed. This approach directed itself at specific factors (particular pollutants) and at the processes that caused their accumulation. In terms of understanding the archaeology of soil chemistry, this seemed to be the best way towards interpreting the evidence. The drawback of the broader spectrum approach is the temptation for the candidate elements, selected from a wide array of results, to be identified, after the completion of soil analysis, on the basis of their correlation with the archaeology. The reason for caution is that the statistical correlation only describes a linear relationship. It does not imply cause and, consequently, can offer no insight into the taphonomy. Where research is limited (by time and materials) to the choice of perhaps a dozen soil factors, greater thought needs to be given to what might be the most likely residues of past human activities. It was concluded that some of these factors could not be reliably assessed by spectroscopic techniques, for example, organic carbon, pH, magnetic susceptibility and, to some extent, phosphorus. It would be less than honest not to admit that had multi-element analysis been easily available I would have been tempted to use it. There were more elements than the limitations of the AAS dictated that I would have included in this study if it had been possible (see Part 6). Further, regardless of my cautionary comments on correlation analysis, this procedure has, in fact, been used extensively (with appropriate qualification) in this thesis.

1.4 MA DISSERTATION

The research presented in this dissertation follows on from an earlier study submitted for a Master's Degree (Jackson, 1997). Two of the sites investigated in the MA dissertation have been researched further, the data re-assessed and the results, together with those for ten other sites, presented here. Apart from the clear association of phosphorus, organic carbon and certain heavy metals with sites of past settlement, the results from the MA dissertation clearly indicated a group of soil factors positively associated with the focus of the settlement and a group that was negatively associated. These groups were labelled "anthropogenic" and "non-anthropogenic" residues respectively – labels that were to prove somewhat of a misnomer (see Part 5, page 219).

These hypothesised groups, however, were subjected to further investigation in this thesis.

1.5 PROPOSED RESEARCH

Soils are, in most cases, biologically active and chemically dynamic. The chemical constitution of soil is essentially pre-determined by natural chemical and biological processes. As has already been stated, where localised variation in the soil chemistry occurs and an explanation unconnected with human activity is not forthcoming, an anthropogenic cause must be sought. It will be demonstrated that in suitable places it is possible to distinguish a pattern of soil elements that is linked to such ancient past activities. The emphasis being on activity (such as domestic occupation, agriculture or industry) and not on precise features. Residues from past human activity leave a persistent record in the chemical composition of the soil. This has been demonstrated by almost 80 years work on soil phosphorus (see Part 2, section 2.6), more recent activity in the field of soil metals, and current work on persistent complex organic residues. Changes to the soil can also be associated with human activities of physical disturbance. These include ditch digging, cultivation and burning which affect the mechanical and electro-magnetic properties of soil. There are other soil changes that warrant more investigation from an archaeological perspective. These include total organic matter content of the soil (loss on ignition) and soil pH.

Proposed Hypothesis:

The chemical composition of soil is altered as a result of the presence of people during some period in the past. These are largely those resulting from the accumulation and relocation of domestic, agricultural (and sometimes industrial) waste. Heavy metals are closely associated with these waste products. Because of the processes of surface relocation by plant and animal activities, measurements of these elements can be made within the top soil horizon and this information (together with independently derived information on soil phosphorus, total soil organic matter and the magnetic properties of the soil) can provide evidence past human settlement and activity. A comprehensive examination of soil qualities can provide a method that will allow the investigator to identify sites of human settlement, determine the geographical extent of human activities and give an insight into the nature of these activities.

The broad objective of the following research is to examine the extent to which an integrated approach to soil analysis can enable archaeologists to,

1) establish whether selected soil-chemical analyses and other soil factors can be used to locate sites of past human activity;

2) identify combinations of soil factors that consistently provide a correlation with past human activity;

3) examine whether such soil measurements can provide additional information about the nature of the past human activity (hereinafter referred to as "type signatures): and

4) formulate a practicable methodology and procedure.

Part Two: Anthropogenic Residues

INTRODUCTION

It is possible to define archaeology as the study of altered environments, the changes to which are attributable to human activity in the past. In such a study one would seek to relate the record as it survives to the past environment from which it was derived and even to speculate on the circumstances which may have created, preserved or eventually destroyed this past environment. One might even attempt to deduce the environment that preceded the first changes attributed to human activity.

The soil itself is just such an environment, subject to human alteration and open to study. It is, however, a dynamic environment, both chemically, physically and biologically, and over time, even without the intervention of humans, it changes. Davies (1980) described soil as a palimpsest: an overwritten record of all the different environmental factors and conditions which have prevailed during its formation and subsequent existence. Where a site has been occupied by people, those environmental factors will also include contributions from human activities during the period of occupation or use.

If changes to soil chemistry are to be used as evidence for past human activity it will be necessary to consider the **causes of change**, that is the activities that generated these changes; the **nature of change**, both in terms of the composition (i.e. qualitative) and the amount (i.e. quantitative) of human residues; and the **fate of human additions** to the soil, how these residues are distributed, redistributed, how they survive, are altered or destroyed.

A wide range of human activities cause disturbance[1] to the physical and chemical properties of soil. When any patterns of disturbance are found the difficulty will be interpreting what particular activity caused the disturbance. It is highly likely that these changes to the soil are greater today (and over the past two hundred years) than at any time previously, if simply as a consequence of increases in population and the development of industry. It also follows that there will be difficulty in distinguishing past events from present, let alone precisely when they happened.

This section will examine the several ways that soil chemistry may have been altered by human activities in the pre-industrial age. The relevance of modern contamination will be considered at the end of Section 2.5.

All of the case studies contained within this dissertation are of small settlements, farmsteads or farms[2] and the reasons for this choice are explained in more detail in Part 3 (see page 111). Briefly they are as follows; accessibility, simplicity, and the avoidance of the worst of modern pollution. But equal to these (and important here) is that for most of human history ordinary folk lived in small, largely self-sustaining, rural communities in which the patterns of behaviour that alter soil chemistry has over the years varied very little. Activities within the settlement are summarised in Table 2.1.

Table 2.1 Human behaviour that can alter soil chemistry

Behaviour	Activity, Process or Usage
disposal	middens, latrines, cess pits, carcass pits, inhumations, cremations
accidental loss	crop and feed spillage, effluent leakage from manure heaps, stockyards, pens, byres and barns
storage & stockpiling	food stores, storage pits, feed clamps, compost & manure heaps
deliberate dispersal	farmyard and garden manure
food / fodder processing	milling, winnowing, butchering, cooking
cottage industry	manufacture of linen, leather, charcoal, metals and pottery
building	timber, wattle, mortar, dung, thatch, ditches, ponds & wells
fire	hearths, forges, kilns, ovens, bonfires, accidental fires, arson.

[1] "Disturbance" to the soil involves the enhancement, dilution or sometimes the depletion of elements as a consequence of human activity – see Part 5, page 211.

[2] Although there is a commonality in all subsistence farming throughout history and throughout the world, there is a diversity in detail that is beyond the compass of this thesis. The comments and evidence presented, unless otherwise stated, refer to past societies within Europe and to a very large extent within the UK.

It will be seen that for the most part these human activities generate organic matter that accumulates and decomposes *in situ*, often close to the focus of occupation. Activities involving burning will destroy organic matter but ash residues will nonetheless accumulate. The main exceptions to *in situ* accumulation are the deliberate dispersal of manures. Particular industrial processes, quarrying, woodland and agricultural activities may well be sited some distance from the focus of settlement.. The actual qualitative composition of anthropogenic soil residues is discussed in Section 2.2.

In practical terms, the soil analyst must be able to recognise the above processes in the observed spatial patterns of soil contamination. Some soil changes will be the result of **focused activities** and associated with discrete locations; a hearth, a byre, a storage pit or a kiln. Others activities, such as **disposal,** (including temporary storage and stockpiling of fuel, food, fodder or manure) will have been located less consistently and the soil evidence of these processes may be overlapping or separated, for example a midden, a compost heap or a bonfire. Then there are those **dispersal** processes, such as manuring and chance spillages which, being much less discrete, nevertheless add to the overall pattern of soil change associated with human settlement.

It is easy to categorise processes associated with human activity but in reality sites become increasingly complex over long periods of occupation, re-occupation and as the result of disturbances (such as erosion, floods, burrowing animals, modern human interference, etc.). The following categories, therefore, are presented purely as a means of clarification and should not be regarded as definitive.

2.1.1 FOCUSED ACTIVITIES

A. Buildings, pens and enclosures: It is not always clear how to interpret the archaeological evidence of vanished settlement structures, particularly in determining their precise function. It becomes more difficult the longer ago the settlement disappeared, especially where most of the materials used were perishable (and also where written records were non-existent or lost). Barker (1985, 13) points out, for example, that on pre-historic sites the square setting of four post holes may be all that remains of a raised granary; or it could be the traces of a dwelling, hayrick, chicken coop, pigsty, a drying or smoking rack or even, for that matter, a lookout tower. A ring of stake holes is usually interpreted as a dwelling, but have sometimes been identified as animal pens or shrines. On reading the literature, it is striking how archaeologists, when discussing the prehistoric period, avoid the use of the word "farm" and refer rather to a "settlement" or a "farmstead". This implies "a domestic rather than an agrarian function" (Piggott, 1981,129). It is, more probably, a reflection of a lack of clear information and inadequate research which makes interpreting functions difficult (Fowler, 1983, 89) . Over recent years there has been a burgeoning interest in prehistoric farming from field, theoretical and experimental archaeologists. But, nevertheless, what does a prehistoric farm amount to archaeologically and how can a pre-historic "settlement" be defined functionally? Today a "farm" can be described as set of buildings each with a specific function (e.g. a house, a barn, a byre, a machinery shed, a dairy etc) exploiting specific aspects of agriculture (e.g. arable, livestock or both) for the purposes of supplying all its produce to the wider community and providing the farmer with an income. A prehistoric "farm" was essentially the same except the community it supplied was contained within the settlement itself and its primary objective was subsistence rather than the production of surplus[3]. Being a subsistence economy prehistoric "farms" were not just agricultural but would also have exploited woodlands, marshlands and rivers and may well have supported their own forge and pottery kiln; may have worked leather, made linen and possibly produced charcoal or, if the location permitted, even salt. They would not only have grown their own food, they would have processed and preserved it as well. This system of total self-sufficiency probably survived well into the historical period, at least in some parts of the UK. Only at times of secure trade (e.g. during the Roman period or after the development of nucleated communities in the late Saxon period) did farms risk

[3] NB. By the late Iron Age, southern England was already trading cereal surpluses with the Roman world (Fowler, 1983, 211).

specialisation and deliberately aim to produce surpluses for sale or exchange outside the immediate community.

In the Roman period the greater use of stone enables an easier recognition or, at least, description of buildings on a rural site (White, 1970; Hingley, 1989). Conformity of design over the geographical spread of Roman influence together with the survival of contemporary historical accounts has assisted interpretation. Nevertheless, there is still much we do not know of the functions and processes that took place in Roman rural settlements and by no means were all "farms" part of the "villa economy" (Hingley, 1989, 11).

In the post-Roman / early-Saxon periods the poor survival of structures and absence of written records makes any interpretation a matter of inference and supposition about the degree of continuity (Finberg, 1972). In the later-Saxon and post-Conquest periods, agriculture, and the communities it supported, became more organised and better recorded (Slicher Van Bath, 1963; Duby, 1968; Astill & Grant, 1988; Sweeny, 1995). The interpretation of the form and function of farms and rural settlements in general became, from then on, increasingly reliable.

Let us consider the least structurally complex of small rural settlements (be it pre-historic, sub-Roman, Dark Age or early medieval) as sites such as these have taken up the main part of this investigation. Apart from building platforms, post-holes, ditches and banks (buried or surviving as earthworks) how might anthropogenic soil residues reveal the location or function of buildings? Organic matter used in construction such as wattle, horse hair in the daub, discarded or collapsed thatch; organically rich in-fills of ditches; debris from minerally exotic building materials, physically altered soils as the result of compaction or burning (i.e. under a hearth) all contribute. So too will domestic contaminants on the surfaces of settlement floors, pens and byres[4] . The construction, occupation and the wide range of activities associated with the farm, with its buildings, pens and enclosures, will have had the potential to generate lasting anthropogenic soil residues.

B. Furnaces, forges and kilns: Industrial processes that use high temperatures such as metal smelting and forging, or the manufacture of lime, pottery, bricks and tiles, require

[4] Bradley (1978, 49) reports small rectangular Iron Age structures at Fengate suitable as byres and associated with high concentrations of phosphate.

the construction of a kiln or furnace and these, and the activities surrounding them, will have left tell tale signs in the soil. Where the volume of production is significant and/or continuous these structures are relatively long lived and can be honestly described as a focused activity. More primitive or opportunistic metal furnaces (and also charcoal pits or stacks), for example, were not permanent features, but, nevertheless, they often occupied regularly revisited locations. Other less industrial processes, such as Roman hypocausts and corn driers will have also left evidence of their operation.

The archaeological evidence for metal working extends over many thousands of years. Since the 7th Millennium BC there has been a continuous technological evolution involving smelting, casting and working techniques. In the UK, metal working equipment and evidence of kilns and forges in the pre-historic period are hard to come by, but examination of the metal artefacts themselves would indicate an increasing sophistication in technology from the beginning of the second millennium BC (Darvill, 1987,101). By the time of the Roman Empire, not only were there highly advanced metallurgical techniques for a wide range of metals (McWhirr, 1982) and their alloys, but exploitation was on a factory scale and the trading of metals and manufactured metal objects (tools, utensils, weapons and ornamentation) was widespread. Nevertheless, the evidence is that small communities, where the requisite materials were available, continued to engage in metal smelting as a domestic activity (Renfrew & Bahn, 1994, 303). This cottage industry continued until the late medieval period when factory centres of the proto-industrial revolution began to form around favoured sites, such as the upper reaches of the river Severn (Hayman & Horton, 1999).

Other high-temperature local industrial processes are mentioned above and include the manufacture of charcoal, lime and the making of pots. Whereas these activities are likely to be sited close the source material (i.e. the nearby woodland, quarry or clay pit), it is not unusual for the last, at least, to be located within the settlement area.

What sort of anthropogenic soil residues are likely to be associated with furnaces, forges and kilns? Until the advances made in the Industrial Revolution, the primary fuel for forge and furnace was charcoal; the presence of charcoal in the surrounding soil might then be expected. At temperatures high enough to smelt/melt metal the vapour pressure density is such that some "fume" is produced in the process. This particulate material escapes with the furnace hot gases and could be dispersed and deposited over a wide area. Waste materials such as clinker would also accumulate and, unless some use was

found for this and it was removed, should be closely associated with the metal working. However, within a particular community that did support metal working it would be difficult to distinguish between furnaces and forges as where the presence of clinker is evidence of the former activity it does not exclude the latter. It is not unreasonable to assume that evidence of the worked metals themselves would give the clearest indication. Industrial residues within soil do occur and large scale enterprises[5] are associated with high levels of local soil contamination set in a wide surrounding zone of more general pollution. High temperatures will also unavoidably alter the magnetic properties of the soil. These physical changes to the soil with the inclusions of charcoal, fragments of burned clay, clinker and ash are what the soil analyst is most likely to encounter when searching for furnace, forges and kilns.

2.1.2 DISPOSAL

In the days before mains sewage and regular refuse collection, the unwanted debris of domestic activities had to be dealt with or life became unpleasant and even dangerous. There are many historical records of this happening quite often in the towns and cities of Britain. How did the communities under consideration in this thesis dispose of human excreta, domestic rubbish and the dead?

A. Human excreta: To nomadic communities the accumulation of human waste is no great problem; it is left behind. Even so, it is and was considered undesirable and unwise to defecate in or too close to the camp site. This behaviour, that is of creating a recognised 'dunging ground', is not peculiar to human beings, but is shared with many other animals. Dung attracts pests, prowling scavengers and predators. To what extent cleanliness (some innate awareness of healthiness, or just an aesthetic preference) was considered a virtue in past societies is conjectural. However, when communities became sedentary, the disposal of human waste did become a problem; a problem that became greater as the size of the settlement grew.

The problem of disposing of human faeces and urine has been addressed in various and in increasingly sophisticated ways. The ***dunging ground*** has not disappeared and can still be an unpleasant discovery for travellers exploring the more impoverished parts of the world or even wandering a few yards from the road-side picnic spots of Britain.

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[5] The lead and zinc workings at Charterhouse on the Mendip Hills have been exploited pretty continuously in the pre-historic, Roman, medieval and industrial periods and heavy metal contamination of soils with atmospheric fall-out (of lead, zinc and cadmium) from smelting extends for many miles.

However, for most settled communities the ***latrine*** was and largely remains the system in most common use. This is a hole or trench in the ground, roughly dug or carefully constructed of stone or brick, with the optional extra of a seat or perch, sometimes covered to provide shelter from the weather, or enclosed for modesty[6]. The nutrient-rich deposits are allowed to accumulate. Both ***quick lime*** and ***ashes*** have been used to absorb the urine, slake the faeces and reduce the odour. These practices are ancient but were still used during the 1960s in the Cornish village where I grew up. Eventually, it becomes necessary to dig out the latrine (or to dig a new trench) and dispose of its deposits on the garden. Those old enough to remember the childhood terrors of the outside privy, especially on a cold winter's night, will recall the relative comfort of the ***chamber pot***. Its use probably dates from the first potter and, where pottery was scarce or unused, the wooden ***privy-bucket*** served instead. The ***earth closet***, a commode with a hopper supplying absorbent and bacterially active soil or ash, was not invented until 1860 (Wright, 1960, 208). But this, like the chamber pot and privy-bucket, had to be emptied outside and, again, probably on the garden. Modesty should not let me minimise the impact of *al fresco* urination which, no doubt, even to this day is a rich source of nitrates and phosphorus in the garden.

The use of a controlled water supply to wash away human excreta entirely, i.e. by ***sluicing*** or ***sewers***, is an ancient practice. The use of both is attested from the ancient cities of Egypt and the Indus, it was a feature in Minoan palaces and taken to a degree of sophistication in many Greek and Roman cities that was not surpassed in western Europe until the 19th Century. The process was dependent on an adequate supply of water; a leat from a river, for example, or a cistern. As such, the process was reserved for the elite or civilised urban communities where imported agricultural produce demanded less self-sufficiency and an otherwise valuable source of manure discarded.

The use of human excreta as a primary source of manure has been a key part of Chinese farming from the earliest times, and remains in high regard to this day (Fenton, 1981, 210). In the west, recycled sewage sludge is a recognised and acceptable source of crop nutrition. In the past, very often the sewage was fed back into the local river or moat, but where this was not possible, desirable, and sometimes deliberately, it was collected in a communal ***cess pit***. This like the latrine would eventually require excavation. In the

[6] The use of communal trench latrines, which were not uncommon in Roman cities or medieval castles and monasteries, for example, would suggest that some of our ancestors were less prim about their bodily functions.

countryside any such usage was limited to villas, to castles and to medieval monasteries. In recent times, where mains water and sewage systems are widely accessible (i.e. from the 19th Century) the modern ***water closet*** (Reyburn, 1969) was adopted.

For the large part, in the small rural communities that are the subject of this study, the sophisticated removal of human waste was neither practicable nor, perhaps, desirable. A subsistence economy, as stated above, could not afford to be profligate with an essential resource.

B. Domestic rubbish: Apart from faeces and urine there are many other waste products that might accumulate within a small settlement. The following is a comprehensive, but not necessarily exhaustive, list.

a. surplus, stale or rotten food
b. unwanted parts of slaughtered animals
c. unusable parts of crop plants (chaff, straw, etc)
d. floor sweepings
e. ashes
f. old floor coverings (rushes and reeds etc.)
g. old thatch
h. wood chopping debris
i. weeds, hedge cuttings, fallen branches
j. broken pots and perished wooden or leather containers.
k. broken or unwanted tools, domestic equipment or furnishings
l. non-salvageable bedding and clothing (textiles, leather, sheep skins etc.)

Essentially, disposal is a function of utility, obsolescence, and convenience. If an item has no direct use; has ceased to be useful; or is just in the way, it is disposed of. How it is disposed of will have a direct bearing on what soil residues might survive. Whether it is abandoned (left where it is), dumped (relocated away from the site), buried, or burned will affect the surviving soil record and influence any interpretation of what event or activity might have created the soil residue in the first place. Where, how often and for how long items of domestic waste are disposed of is also of great relevance. Regular deposition in the same place (be it a Neolithic feasting site, a Roman herb ***garden*** or a Viking ***midden***), will result in the accumulation of considerable amounts of organic debris and leave a persistent residue in the soil. Regularly removing rotted-down domestic waste from a ***compost heap*** to manure gardens or fields will reduce the potential for soil enrichment beneath the heap as will any regular relocation of the site. Burning domestic waste on a ***bonfire***, apart from the loss of oxidised carbon.

will not in itself affect the accumulation of other elements, such as phosphorus or heavy metals. Burning will, however, render some elements more soil-mobile[7]. Indeed it is the release of available plant nutrients that makes ash a useful addition to manure. The removal of ashes and the re-siting of the bonfire will, as in the case of shifting compost heaps, also affect the quantity of residues in the soil beneath.

Middens; A colloquial definition of a midden is a dung heap. To an archaeologist the term broadly covers any deliberate assemblage of domestic debris. Classic examples would be the pre-historic heaps of discarded shells left at littoral feasting sites, or the in-filled pits that surround many Iron Age settlements[8]. There have been attempts to define middens more precisely, one of the more recent of which was presented by researchers at the British Museum (Needham & Spence, 1997). When one attempts to categorise the patterns of refuse accumulation, the taphonomy of middens becomes dauntingly complex. Needham and Spence do present, however, a simple classification of midden function which I summarise as;

a) ***stock piles*** of economic resources (a manure heap, fire wood etc);
b) ***spoil heaps*** of process-waste (shell middens, flint knappings, etc);
c) ***tips*** of gathered material for purposes of tidiness; and the obtuse concept of
d) ***trophies***, i.e. middens as symbols of status or power.

In this thesis I distinguished only between the accumulation of re-cycleable material (*manure heaps, compost heaps*, etc) and the piles of domestic rubbish composed of relatively permanent and un-recycled material (which I call *middens*). Middens can survive as a recognisable feature and equate well with the refuse infill sites upon which so many modern housing estates are built. On the small rural holdings covered in this study, middens as such, might be small and possibly indistinguishable from the remains of the manure or compost heap.

Bonfires; Any domestic waste that is directly compostable will be thrown on the compost heap whereas material potentially useful as fuel (e.g. chopped wood, dried dung, etc) is for the domestic hearth, forge or kiln. The rest went into the midden or, if it

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[7] Burning will also produce insoluble oxides such as Zn O and, to a lesser degree, Pb O.
[8] The multiplicity of pits surrounding many Iron Age settlements (Fowler, 1983, 169) full of artifactual residues might suggest a profligacy with a potential source of manure especially if there were already a surplus of food production. On the other hand it might well demonstrate a clear functional difference between a midden and a manure heap.

was combustible (waste woody material, large bones, old fabrics, chicken feathers etc), the bonfire. The ash from such fires would be rich in plant nutrients and either added to the manure heap or spread directly onto the land. As would that from the domestic hearth and the feast (more generous supplies of wood may have been burnt if the fire had a festive or ceremonial purpose). Ash from all these fires was also added to bedding in byres and stables (Fenton, 1981, 211), and to privies to absorb fluids and reduce odours before finding its way to the compost heap.

Compost heaps; The composting of manure and waste was an agricultural craft and is recorded from the earliest times (see below). The contents of the compost heap were more widely dispersed and the recovery of the more durable constituents (rolled and worn pottery shards, pieces of clay pipe etc) can testify to the extent of this dispersal. Even if the contents of the compost heap were only temporarily located, the continual leakage from the base and the activity of soil fauna (e.g. earthworms) would have altered the qualities of the soil beneath, perhaps sufficiently to be recognised by a soil analyst even after a long period of time.

Gardens, allotments, tofts; There has long been a clear definition between food plants grown in the field and those grown in the garden; agriculture and horticulture. The former were exclusively[9] and generally remain, cereals (e.g. wheat, oats, barley, maize, rice, sorghum, millet etc). Cereal crops provided the staple diet of the community, but the survival qualities of dried grain allowed surpluses to be stored and exchanged in trade or as levy payments. The importance of grain led to it being grown on an extensive scale and engendered a communal responsibility for its culture, harvest and storage; labour requirements being seasonal. Arable farming brought with it its own problems which are discussed more fully below. The closer surrounds of the settlement were used differently. Here was a convenient place to grow vegetables and herbs (and even fruit trees – see below). The immediate surrounds of the farmstead were easier to keep fertile. Any domestic waste that could not be fed to farmyard livestock could be thrown on the garden. House sweepings and dust were considered valuable source of plant nutrition by the Romans and mention has already been made of the contents of the chamber pot and privy. It should come as no surprise to the soil analyst to find a "halo"

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[9] The advent of cash cropping (particularly in southern hemisphere economies desperate for revenue) and, more recently, the growing on a field-scale of vegetables (e.g. potatoes, peas and beans etc.) in western Europe and North America, have, to some extent, displaced cereal crops from the rotation.

(Bintliff *et al* , 1990) of enrichment surrounding or adjoining the main focus of settlement.

Dead bodies: The final category of domestic waste to be considered is dead bodies. Their disposal is regarded somewhat differently. For cultural and spiritual reasons and in most societies human corpses are treated deferentially and removed to sacred ground. The whole body or the burned ashes are left exposed to the air, buried or entombed. Sometimes the body is embalmed or mummified to prevent decay. As to the accumulation of detectable soil residues it matters little whether a body is buried or burned. Only if parts are removed (by scavengers or archaeologists) or the remains are prevented from mixing with the soil (being mummified, entombed or otherwise contained) will soil enrichment be affected.

In terms of organic matter and associated elements, a single human body left to decay does not, over time, leave as much soil evidence as a manure heap or a latrine (see Section 2.3). But where a community has resided for many generations a well used (and re-used) grave yard will demonstrate markedly altered soils.

In certain cases dead animals are interred rather than recycled. This can be part of a cultural practice, or a consequence of infectious disease (murrain, plague etc). Such carcass pits (as grain pits) are often very deep and are unlikely to be obvious to the soil analyst unless a large number of cattle were interred or the old pit used as a midden.

2.1.3. DISPERSAL

In any subsistence community there is no room for wastage. Nothing is discarded, everything is recycled. The residues of consumption are, literally, ploughed back into production. The principal sources of organic manure, be it for the field or garden have been, over our history, the faeces and urine of domestic livestock. Other important sources include crop residues, vegetation debris, animal bedding, human ordure, ashes and domestic waste. To understand how the dispersal of manure affects the soil it is necessary to understand the principals and practices of manuring itself.

A. The maintenance of soil fertility : Beyond the self-replenishing, consistently-fertile river deltas and flood plains of the Nile, Tigris and Euphrates valleys (the "fertile crescent"), the earliest farmers of north west Europe would have discovered that the nutritive qualities of the soil diminish with repeated cropping. Either new land had to be found or the soil topped-up with exogenous plant nutrients (Bradley, 1978, 15). For

nomadic communities, where the vegetation was sufficient, ash from burning the cleared trees and brushwood would have sustained a crop or two before relocation became necessary. For sedentary farmers the supply of available wood ash would soon have become limited. Human excrement and household refuse and dung from livestock was the next most obvious source of plant nutrition. As communities grew, however, so did the area of surrounding agricultural land required to sustain them. The extended area of cropping required an increased supply of manure. The distances over which the manure had to be transported increased as well. Both these factors imposed constraints on farming practice which, over the years, have been dealt with in various ways; crop rotation, the use of soil nitrifying crops, selective usage of manure, dunging, and seeking alternative methods of soil improvement. However, the main problem was paradoxical. The primary source of manure was animal dung. The production of dung depended on how adequately the animals were fed. Crop production, to first satisfy human needs and then animal fodder, was limited by the fertility of the ground, the main supplement to which was animal dung. The solution to manure limitation was found in extending the agricultural area even further and allowing land to fallow. Nonetheless, the extension of the cropping area only exacerbated the manure shortage.

B. Manuring practices: The earliest tentative evidence, so far, of manuring fields in western Europe is in the late Neolithic period. Dutch workers (Fokkens, 1982) recovered charred grain and flint/pottery fragments indicating the spread of domestic refuse. Further work in Holland (Bakels, 1997) on a middle to late Bronze Age buried field system, using the evidence of soil physical properties and plant and insect remains, showed that domestic refuse and ditch dredgings had been applied to the land over a long period of time. As has been mentioned in Part 1, there is, in Britain, ongoing research into the physical and chemical properties (particle size analysis, carbon isotopes, faecal lipids) of less ancient manured soils and which is already throwing light on past manuring practices.

With the exception of the faecal lipid work (Bethel *et al*, 1994; Evershed *et al*, 1997; Simpson *et al*, 1998; Bull *et al*, 1999) the evidence is for the use of domestic waste, turf, marl, ditch or marsh mud, sand or seaweed. Yet, over the ages, it is reasonable to assume that soil fertility was maintained using dung-based manures primarily derived from livestock. The livestock husbandry practices adopted in each situation or time period will have influenced the manuring practice, which, in turn, will affect the type and extent of soil residues that may have survived.

Bone assemblages[10] examined in the remains of prehistoric farms in Europe have consistently revealed the dominance of cattle, pigs, sheep and goats, with poultry (the domestic hen, geese and wild ducks) showing a fairly regular presence (Grigson, 1982; Crabtree, 1989). The horse turning up as a minor player. There are, of course, bones of wild animals but these animals are not manure contributors. A study of bone assemblages at pre-historic sites in England (Grigson, 1982, 306-307) indicated that cattle were the dominant domestic animal in the Neolithic (3000 – 2500 BC). Traction, almost certainly, remained the main function of cattle from the development of the prehistoric ard to the introduction of the mouldboard plough (Rees, 1981, 7 ; Bradley, 1978, 39) during the Roman period (and indeed through into the Middle Ages[11]). Draft oxen (like modern tractors) were the mainstay of arable farming. They had to be properly fed and safely over-wintered. Grigson's bones also indicated a greater survival age of cows suggesting cattle were kept for their milk. The drinking of cows milk in pre-Roman Britain was recorded by Caesar and Strabo (Piggott, 1981, 50). For dairy cattle to be productive they also need to be fed well and corralled or housed over winter. As a consequence oxen and milking cows generated a large amount of dung close to the farmstead[12].

Cattle may well have been the dominant domestic animal in Neolithic Britain, but by the early Bronze Age (2000 – 1500) cattle had given away to pigs. Grigson argues (op.cit., 308) that this was a result of woodland clearance and the proliferation of bracken. Bracken is readily eaten by pigs, but not by cattle, sheep or horses to whom it is poisonous. The view is (Barker, 1985, 35) that pigs were farmed semi-wild in the forest or allowed to forage for themselves on the edge of the settlement. Although there is no direct evidence, penning pigs, over the winter months at least, may well have been practised. As such they would have been a source of manure.

Within the continent of Europe as a whole, sheep (and goats), from the pre-historic to the present day, were the most consistent provider of meat and dairy products as well as

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[10] Bone assemblages, like any archaeological evidence, are only indicative of what survives and also cannot pre-suppose the selectivity of deposition (Payne, 1972). Cattle bones, for example, may be under represented because they were burned ("*bonfires*") rather than buried. There are sometimes great discrepancies between the archaeological remains and the historical record (Albarella, 1999)

[11] Oxen were still being used in parts of western Europe in the last century.

[12] In some woodless pre-historic situations, e.g. the Scottish Islands, cattle dung was valued more as a fuel that as a manure (Barker, 1985; Fenton, 1981, 210)

wool and tallow. The manure they produced was also valued. Although extensive foragers, the practice of corralling sheep for shearing was almost certainly observed in pre-historic Britain.

The surviving commentaries on Roman agriculture are extensive[13] and remained (or at least were rediscovered as) the authoritative sources in the later middle ages. The advice on manuring, composting and livestock management was detailed and precise. The considerable interest Roman commentators expressed in the maintenance of soil fertility reflected the general scarcity of manure. In Britain agricultural improvement was not universal, the evidence, so far, would suggest that most innovation took place on the larger estates in southern Britain (Jones, 1981, 104).

The ox continued to be the puller of plough and cart throughout the Roman period. It is evident that the Romans of southern Europe ate little beef and regarded bovine dairy products as outlandish[14] (White, 1970, 277). In Roman Britain things were different. That cattle were over-wintered in numbers is witnessed by the evidence of surviving turnip seeds (Finberg, 1972). Turnips require 1.5 tonnes of manure per hectare to grow at all successfully, and clamped turnips provide good winter fodder for livestock.

In the Roman period pigs were penned and fed scraps for part of the year and taken out for pannage at the appropriate time (Finberg, 1972). Many swine were also kept semi-wild in local woods or forest. The traditional husbandry practices for sheep, it seems, continued unabated.

For much of Roman Europe, sheep (and goats) were the probably the primary dairy animals, although direct evidence is circumstantial (White, 1970). As such they will have received supplements to their natural diet, particularly in the winter months, and, on the bigger farms, housed or penned, at least overnight. Stall-fed sheep would have been significant sources of manure.

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[13] The Roman writers such as Cato (*De Agri Cultura*); Varro (*De Re Rustica*); Columella (*De Re Rustica* and *De Arboribus*); Pliny the Elder (*Historia Naturalis*); and Palladius (*Opus Agriculturae*) are among the best known, but there were many others. Although these writers drew to some extent on earlier Greek and Phoenician traditions, for the most part their ideas and guidance were based on practical farming and first hand experience.

[14] The drinking of milk is considered evolutionarily " a late and restricted feature of diet" and worldwide, lactose intolerance (particularly of cow's milk) is still quite common (Sherratt, 1981, 276).

When Roman influence declined from the 5th Century onwards, some suggest that good farming practice deteriorated and, with little surplus product, cattle fodder became in short supply. The use of what little there was had to be prioritised " – *virtually anything edible would be fed to the plough oxen to keep them alive through the summer*" (Barker, 53, 1985). The continuity of manuring practices in northern Europe after the Roman period has also been questioned. Sweeney (1995, 29) argues there is little historical evidence for manure management or the systematic manuring of land before the tenth century and that this might have been a function of the number of cattle that could be over-wintered. Interestingly, Sweeney suggests that soil analysis might be able to throw more light on the subject. There is, however, another view that in post-Roman / early Saxon England farming practices, at first, changed very little although the volume and extent of production fell (Piggott, 1981, 345).

Excavations on an early Saxon (AD 400 – AD 650) village at West Stow, Suffolk (Crabtree, 1989) provided one of the largest and best preserved faunal assemblages that has been analysed in Britain. Bones recovered confirmed that the main domestic animals present were still sheep, cattle and pigs. There was also evidence of poultry, goats and a small number of horses[15]. Cows were still kept primarily to breed replacement oxen. There is very little evidence they were kept solely for milk before the 11th Century[16] (Piggott, 1981, 349).

Trow-Smith (1957, 85) presented evidence that pannage for pigs increased in the 7th Century but, as the woods were cleared, pig populations declined. At the same time there appeared to be a compensatory increase in domestic cattle (Crabtree, 1989). Since early historic time (and as recently as the 18th Century) pig husbandry in England remained dependent on seasonal pannage although the animals were often penned at night and over-wintered in sties and pens. (Grigson, 1982, 300).

In the later medieval period shortage of manure continues to place constraints on farming. The French historian, Georges Duby (1968, 24), cites the western European practice during the tenth and eleventh centuries of thin sowing and long fallow periods.

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[15] The horse was not used regularly as an agricultural animal until relatively modern times.

[16] In medieval England cows milk and cheese were produced and consumed locally by farmers and cottagers but not really marketed on any scale until the 17th Century (Slicher Van Bath, 1963, 283). It was a further two hundred years before cows milk became widely accepted as a safe food source.

This he suggests was not only due to inadequate tools for cultivation, but also to the "*virtual absence of manure*". Duby argued that this critical lack of available manure largely accounted for the enormous size of fallowed areas.

From pre-historic to medieval times there was a chronic shortage of manure. This state of affairs persisted until the gradual improvement of agricultural practice in the post-medieval period. Then, with the advent of new crop rotational practices, the introduction of soil nitrifying crops and the burgeoning market for agricultural produce in the 18th Century, the situation changed. The growth of well fed dairy herds began to produce greater quantities of farm yard manure and the ancient spiral of negative returns was broken. Ironically, after millennia of shortage, the heyday of manure probably lasted a little over a hundred years … until the arrival of mineral and synthetic fertilisers. Today, in Britain, a surplus of cow dung is no longer regarded as a boon; the disposal of cattle effluent has, to the dairy farmer, become an economic burden and an environmental embarrassment.

C. Some other kinds of dispersal: Animal dung in the form of manure may also be redistributed to meet the requirements of social status. For example, medieval manorial systems required peasants to manure the Lord of the Manor's demesne lands before they attended to their own. Redistribution of soil enriching deposits are not always a consequence of dispersal. Feeding stalled or stockaded animals by, for example by importing quantities of elm or holly shoots as fodder, will redistribute woodland nutrients to the stall or stockade.

D. The relative qualities of dung: The recognition of soil residues attributable to manure will depend on the quality of the feedstuff provided as well as the quantity. The qualities of animal manure are a reflection of diet. The Roman agriculturalists were great authorities (not always in agreement) on the relevant merits of animal faeces used in manure production. Poultry manure was the most highly rated (particularly that of thrushes and blackbirds (!) according to Varro, Book I, 38, 2). All were agreed that the droppings of ducks and geese were not of an acceptable quality, probably because they were to a greater extent herbivorous animals. Manure from sheep and goats was rated next followed by that of donkeys and horses. The quality of pig manure was in some dispute. Being omnivorous but penned, it all depended on what they were being fed at the time. Cattle manure, for Varro at least, came last. Other than those used for draught, cattle, in much of the Empire, were poorly fed. Non-working cattle were foragers and

herded as such. Their diet was often of poor quality and opportunistic. But this was not the situation everywhere. In Britain (see above) cattle manure, especially when composted with straw, was rated more highly (Fenton, 1981, 210).

Roman muck-lore was apparently lost for centuries and rediscovered during the Renaissance. Fussell (1955, 106) describes Tudor and early Stuart England as a period of a growing intelligent approach to crop nutrition but where practice still lagged behind. As to the quality of dung there was a general re-iteration of their Roman forbears; that of pigeons and poultry was held in high regard followed by human ordure (preferably mixed with other household waste). Horses, sheep and pigs came somewhere next, and that of cattle last. Thomas Hyll in 1563 (Fussell, 1955, 103) extolled the virtues of asses dung being weed-seed free. The heyday of cattle dung based farm yard manure had to wait a century or two.

E. Composting: To the manure heap was added the other domestic waste products and anything else that would rot down. Composting potential plant nutrients became a practised art. In the days of Julius Caesar, Marcus Terentius Varro, Rome's first public librarian, but a farmer in his own right (I,13,4) advised that "*close beside the farmstead there should be two manure heaps ...*" one for composted manure and one for composting manure. The object was a more efficient usage of a limited resource. Varro provided precise details of the composting procedure and a list of suitable ingredients including plant debris, ashes, sewage sludge and house sweepings.

There is historical evidence that farmers in the 16th Century were composting what dung there was with earth, ditch diggings and, where available, seaweed, sea sand or turf to bulk up the manure (Fussell, 1955, 98). The use of turf as a manure, either composted or burnt, could possibly been a much older practice (Fenton, 1981, 212).

F. Direct dunging: A distinction needs to be made between *manuring* and *dunging*. Manuring is the deliberate spreading on the land by the farmer of plant nutritious waste, often a composted mixture of materials. Dunging is the natural dropping of faeces by animals onto the land, although their presence there is contrived by man. Except for the penning and corralling of animals in the farmyard, for a large part of agricultural history, domestic livestock, although under supervision, ranged freely in search of forage. To what extent livestock were used before the Middle ages to dung fields before

they were ploughed is not known. Almost certainly they would have been excluded from the land under cultivation. During the later middle ages, where fallow fields had been enclosed, sheep were often used to dung the land prior to ploughing (Fussell, 1955, 96). Closer to home sheep were often grazed in the enclosed orchards next to the farm or croft. This was practised in medieval England and consistently into the middle of the last century. Introducing sheep into the immature cereal crop, especially where mild winter weather has led to prolific growth and increased the risk of later lodging; under-sowing cereals with grass or stubble turnips to provide post-harvest forage; or even just grazing the stubble before ploughing, is still practised today. However, for probably a greater part of the agricultural history of western Europe cattle were foragers of waste land and the woodland edge or the uncultivated commons. What dung was dropped was widely scattered and fell on land that was never cropped.

G. Other sources of soil improvement: Materials other than dung-derived manure have been used in the past to improve the fertility of the land. There is clear archaeological evidence (Simpson, 1997 & Simpson *et al* 1998 a&b) of the use of turf, peat ash and seaweed in Orkney and Norway in the early medieval period. Being in an area beyond the direct influences of Roman civilisation suggests these sources of soil improvement were quite ancient and may well have been pre-historic in origin. The introduction of nitrifying crops into the rotation is often thought of as a recent development (late 17th Century), but peas and beans were grown by pre-historic farmers ((Reynolds, 1987, 33; Fowler, 1983, 163) and there is some evidence that Roman farmers deliberately intercropped pulses with cereals (Jarman, 1982, 142). The addition of clay (*marling*) and lime to improve soil quality were practised by Romano British and medieval farmers[17]. The practice may have even been pre-historic[18]. Liming became more common in England from the later 17th Century on with the increasing availability of coal to fuel kilns. It is still practised today. Marling managed to survive into the 19th Century (Mingay, 1977, 35).

H. Soil residues patterns resulting from the practice of manuring:

Surviving residues from manuring are more likely to be found where application has been intense or prolonged, i.e. simply a function of the quantity of manure applied to

[17] Fussell (1955, 97) records the disquiet of one early 16th Century agricultural commentator at the discontinuation of marling by farmers who were fearful that by improving their land they would suffer increased rents.

the ground. It is also, quite clearly, a function of the length of time that has elapsed since deposition over which natural depletion will take place. This principle, of course, applies to the survival of all anthropogenic residues and is addressed in Section 2.3.

The above review of manuring practices has emphasised that this source of soil fertility has often been scarce since pre-historic times. It might appear to follow that, because of this scarcity, the constant depletion of soil nutrients by crop plants will have rendered any recognition of the activity impossible. It will be explained in Section 2.4 that some components of manure are either not required by the crop or, even if they are, become fixed and unavailable. So scarcity, in itself, does not mitigate against detectability.

The patterns of manure-derived anthropogenic residues will depend upon the method of dispersal. Thin scatterings on large fields will leave a less pronounced and more diffuse record than on the more regularly manured garden. Patterns left by the manure heap itself are discussed above.

The questions also arise of whether the type of livestock farming employed affects the pattern and distribution of anthropogenic residues (i.e. animal species, dung quality etc) and whether different patterns can be associated with different practices and at different periods in our history?

If livestock are foraged extensively and separated from the farm and arable fields, they will not contribute to the manuring process. Only when livestock are stalled, penned or corralled will the collection of manure be practicable. This was the case with the overwintering of oxen, dairy cattle and essential breeding stock (be they cattle, sheep, pigs or poultry). Obviously, confining animals is more widely practised in the colder north or in mountainous areas. Over-night stalling or penning of livestock also would have facilitated the collection of dung.

As to dung quality, it is not only the relative amounts of plant nutrients in the faeces that matters, it is also about fibre content and how well the faeces composts. These qualities are themselves determined by what is eaten and how well it is digested. Cattle are far more efficient at digesting plant material than sheep or horses, consequently their faeces

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[18] Bradley (1978, 44) suggests that "working hollows", first recorded in late Bronze Age/ early Iron Age settlements, may have been marl pits. Fowler (1983, 170) also promulgates the pre-historic use of marl (and also chalk) as a means of soil improvement.

makes poorer manure. Pigs in sties and poultry, being omnivorous and often fed on a wide range of food types, are more likely to produce faeces rich in plant nutrients. The chemical composition of faeces is discussed in Section 2.2.

As to the effect of manuring practices on surviving soil residues, once again it is a matter of quantity. All things being equal, periods of high farming (e.g. Roman southern Britain, 19th Century England) might be expected to leave better evidence.

Finally it is asked whether composting, direct dunging or other (non-livestock) methods of improving the soil have a bearing on what is found by soil analysts?
The compost heap, being the recipient often of midden material as well, plays a key role in understanding manuring patterns. The scatter of the non-compostable fragments of pottery contained within the manure allows the archaeologist to define the limits and intensity of manuring. As to dunging, liming and marling, these processes should in theory be detectable but probably lie at the margins of our skill to do so.

SUMMARY

This Section has examined some of the past activities associated with small self-sustaining rural settlements and has considered how, through these processes, anthropogenic soil residues might accumulate. On reviewing the evidence it is concluded that these organic deposits are mostly associated with focused activities in buildings, pens, furnaces, kilns and forges; with the disposal of human excreta, domestic waste and dead bodies; and with the dispersal of manure and animal dung on gardens and fields. The next Section will consider the qualitative composition of these anthropogenic residues.

SECTION 2.2 THE COMPOSITION OF ANTHROPOGENIC SOIL DEPOSITS

There are a wide variety of processes that give rise to anthropogenic deposits; and it is the chemistry of the residues surviving from these deposits that concerns this research. This Section examines the chemical composition of faeces, urine, of composted domestic rubbish, of dead bodies, wood ash and industrial spoil. What happens to these deposits over time is discussed in Section 2.4.

It is necessary to point out that any attempt to provide empirical data on the composition of anthropogenic waste will meet with difficulty. This is largely because composition is a product of many variable factors and can only be defined within a wide range of values. It is also because most of the scientific research carried out to date has been selective and specific, i.e. biased towards the dietary, health and environmental pollution affects on humans, domestic animals or crop plants. Such research, not unsurprisingly, tends to neglect or ignore those attributes of anthropogenic waste which it judges less relevant.

2.2.1. HUMAN FAECES AND URINE

The **reference**[19] adult human excretes 135 g (60 – 500g) of faeces per day. The weight varies with intake, being greater with vegetarian diets. The composition of human faeces is also variable, but for reference man 80% of this weight is water, the rest being 13% ash[20], 5% fat, and the remaining 2% made up of protein, partially degraded celluloses, poly-saccharides, bacterial debris and other undigested food residues. Again, with diets of a lesser or a greater meat content, these proportions will vary, but not significantly (Snyder *et al*, 1975).

The volume of urine produced daily by humans is affected by body size; water, salt and protein intake; ambient temperature; exercise and sweating. For reference man the daily volume is 1400 ml (500 –2900 ml). Urine is 94.2% (90% - 98%) water. The largest component of the remaining 5.8% ("solids") is urea (1.6%). The rest is composed of small amounts of metabolic hydrocarbons (enzymes, hormones, amino acids, surplus

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[19] All the data relating to humans is taken from the "Report of the Task Group on Reference Man" which is a unique and comprehensive collection of empirical data published for the International Commission on Radiological Protection in 1975. They are not actually average data but data chosen as useful reference points.

[20] The term "ash" is used in its bio-medical and veterinary sense as the ***mineral*** content of tissue or other bio-matter. It has traditionally been estimated by a process of ignition.

vitamins etc.) and various electrolytes. These electrolytes are mostly chlorine, sodium, potassium, sulphur, phosphorus, calcium and magnesium. Small quantities of the heavy metals cobalt, copper, lead, manganese, nickel and zinc are also present.

The table presented below shows the daily intake and excretion rates of a selected range of metals and phosphorus for an average human being (Snyder *et al*, 1975). Four elements show very high rates of intake and excretion, phosphorus, zinc, manganese and copper; nickel and lead show intermediate levels and cadmium, chromium and cobalt relatively low levels (see Table 2.2).

Table 2.2 **Daily intake and excretion rates of certain elements by reference man** (from Snyder *et al* (1975).

Element	*Intake*	*Excretion*		
		Urine	*Faeces*	*Other**
	ug/day	*ug/day*	*ug/day*	*ug/day*
Cadmium	150	100	50	-
Chromium	150	70	80	-
Cobalt	300	200	90	10
Copper	3500	50	3400	50
Lead	440	45	300	95
Manganese	3700	30	3600	70
Molybdenum	300	150	120	30
Nickel	400	11	370	19
Zinc	13000	500	11000	1500
Phosphorus	1400000	900000	500000	-

* mostly sweat but also hair, nails, menstrual & seminal secretions, and milk.

The great interest in soil phosphate as an archaeological indicator is reflected in the relatively large amounts of phosphorus excreted (1.4g per day). The intake and excretion-rates of all these elements will vary with diet. Those shown are based on modern day diets, so that in an archaeological context the data for each element should be treated on a comparative and order of magnitude basis. A cautionary note needs to be entered here, particularly in the case of lead, as there is evidence (Gifilan, 1965) that dietary intakes for specific elements could have been significantly different in the past (see page 36).

To complete the picture, humans also excrete by sweating and by shedding hair and dead skin. Anthropogenic deposits accruing from these processes should not be underestimated. For example at high temperatures or as a result of engaging in heavy activity an adult male can produce as much as 15 litres of sweat in a day. Sweat loss significantly affects the balance of sodium, chloride, potassium, iron and (in the case of low protein diets) nitrogen. Sweat also contains smaller proportions of phosphorus and heavy metals.

2.2.2. LIVESTOCK FAECES AND URINE

The amount of faeces and urine produced by domestic livestock varies not only with species but is also dependent on the system of livestock production adopted. Again empirical data relevant to the sorts of small rural settlements discussed in this thesis are hard to come by. As a rough guide, some recalculation of other published data would indicate the following outputs (see Table 2.3).

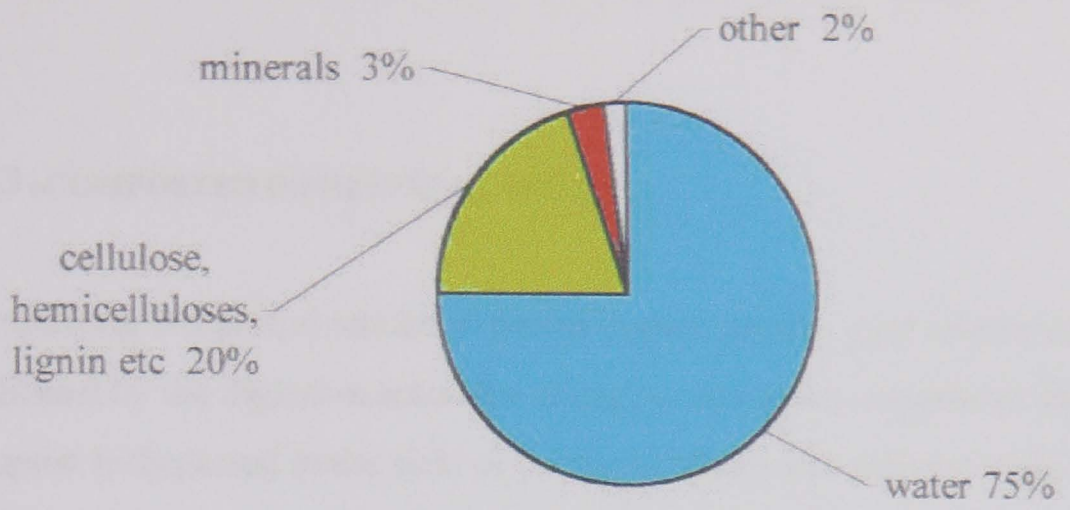
Table 2.3 Daily output of faeces and urine (kg)

Animal	*Faeces*	*Urine*	*Total*
horse	10	2.5	12.5
cow	13	5.5	18.5
sheep	1.2	0.6	1.8
pig	3.5	2.5	6.0
hen	*	*	0.05

(calculated from Cook and Heizer, 1965 - after Bell, Davidson and Scarborough 1961, Thorne 1941 & Van Slyke 1932)

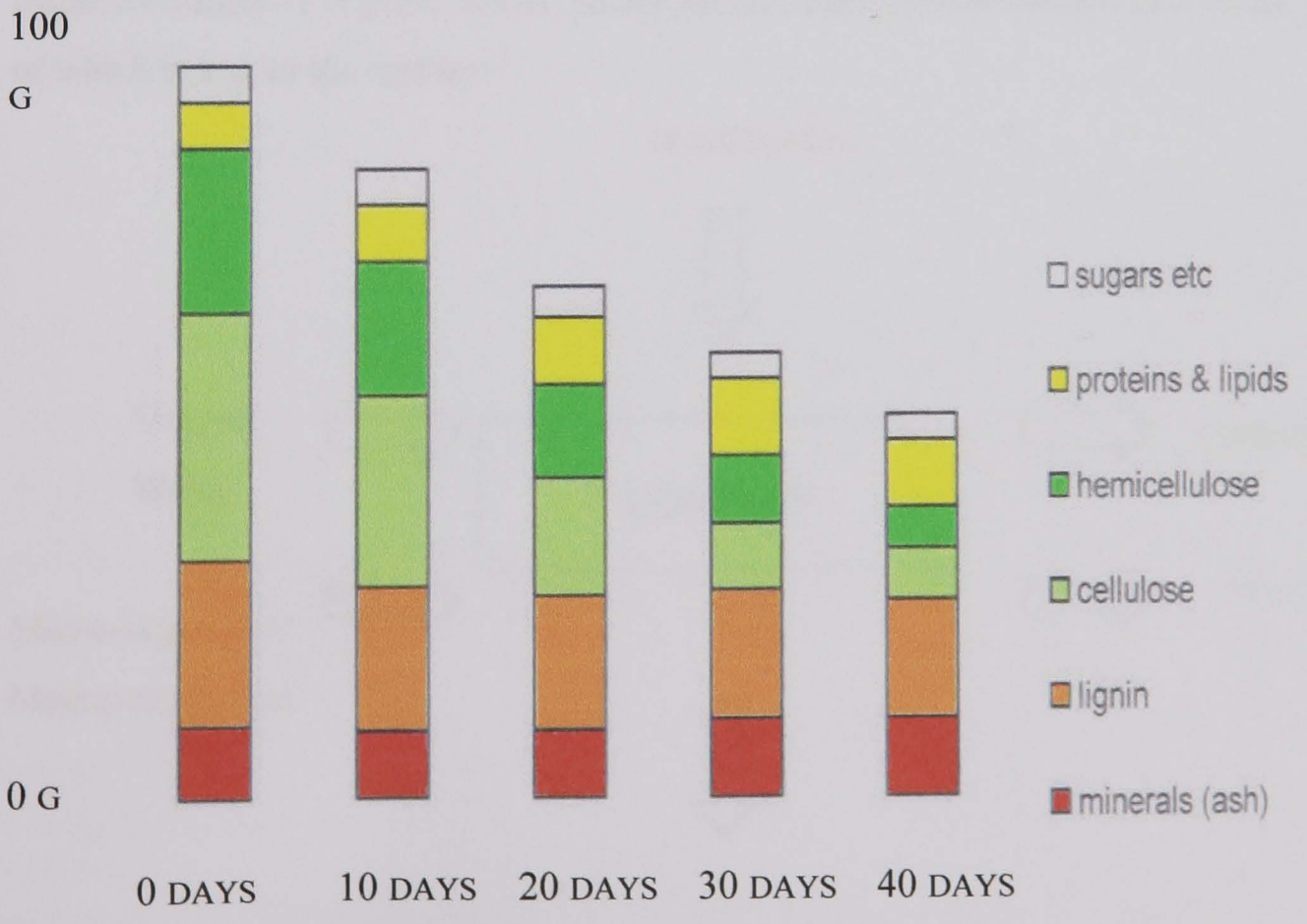
Again estimating the composition of faeces and urine for the different species is difficult, but the following generalised data for herbivore faeces should present a fair approximation. The basic composition of herbivore urine, although varying in certain metabolic hydrocarbons, will not differ greatly from that of man given above.

Figure 2.1 Composition of herbivore faeces *(after Lodha, 1974)*



The extent to which herbivores succeed in digesting their diet depends on the species. Amongst domestic livestock, cattle are more efficient than horses for example. Horse dung remains rich in partially digested herbage. The following chart illustrates the gradual decomposition of such dung after being dropped by the animal.

Figure 2.2 Decomposition of horse dung ***(after Lodha, 1974)***



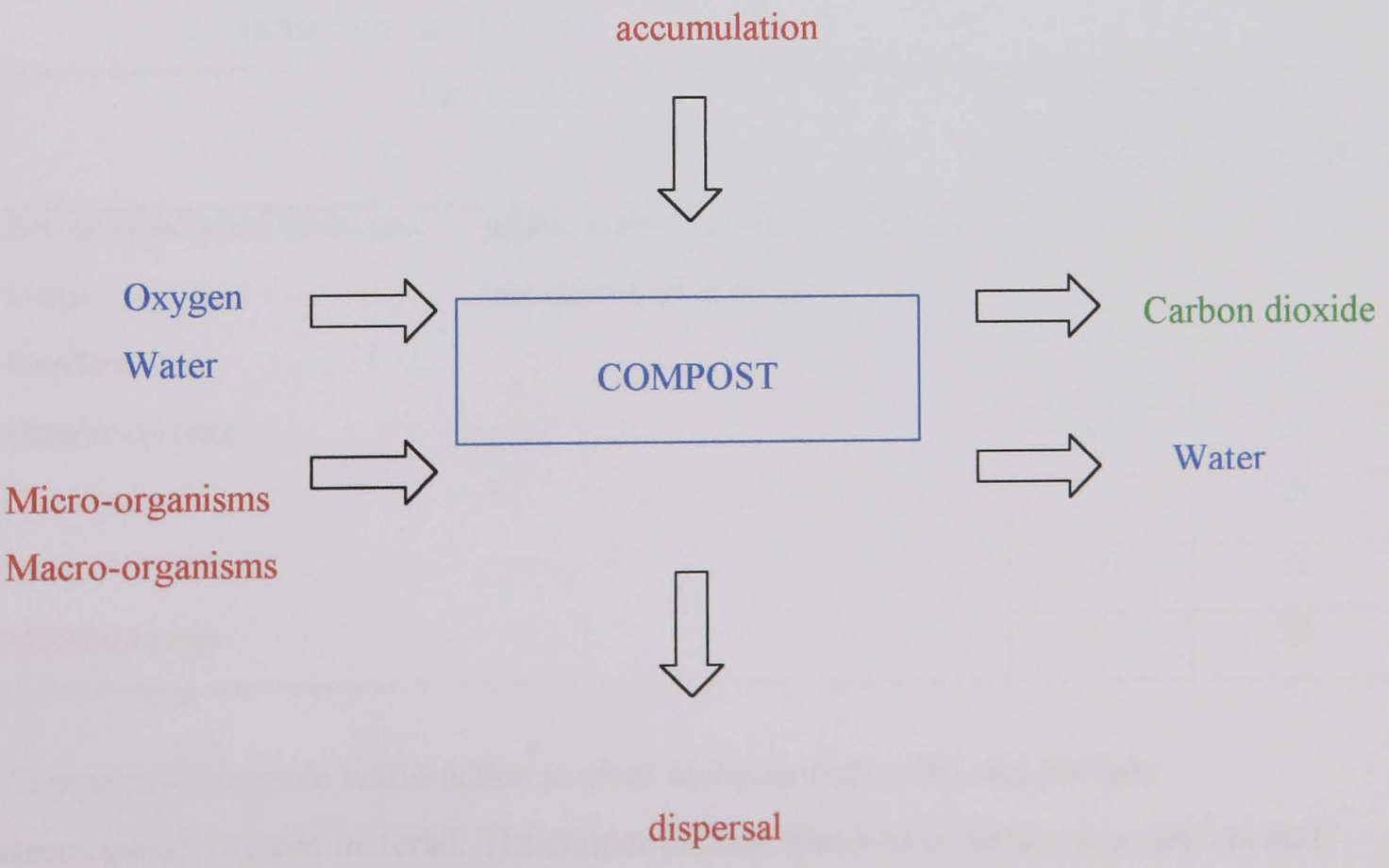
It can be seen as the less resistant plant matter is decomposed (converted into other bio-mass (micro-organisms) but eventually expelled as carbon dioxide and water) by soil

organisms the relative concentration of surviving minerals increases. These minerals include potassium, phosphorus, calcium and magnesium, but also sulphur, chlorine and small quantities of the heavy metals cobalt, copper, lead, manganese, nickel and zinc.

2.2.3 COMPOSTED DOMESTIC RUBBISH

Composting is a partial oxidation process (part aerobic, part anaerobic) which is facilitated by the digestive activities of micro- and meso-organisms. By the time the compost is dispersed in the field or on the garden it will still comprise of much undigested matter as well as released plant nutrients. No compost will be exactly the same and the accumulated constituents may differ widely. The products of composting are, however, remarkably similar (see below). Composted domestic rubbish is likely to be some combination of crop residues (chaff, etc), dust, cinders and ashes, wastes food, bone and offal, wood shavings and sawdust, human faeces, animal dung and bedding and other plant material (bracken, seaweed, twigs and leaves, etc). The organisms that enable the organic components of the compost heap to break down include bacteria, fungi, nematodes, ants, springtails, millipedes, woodlice and earthworms.

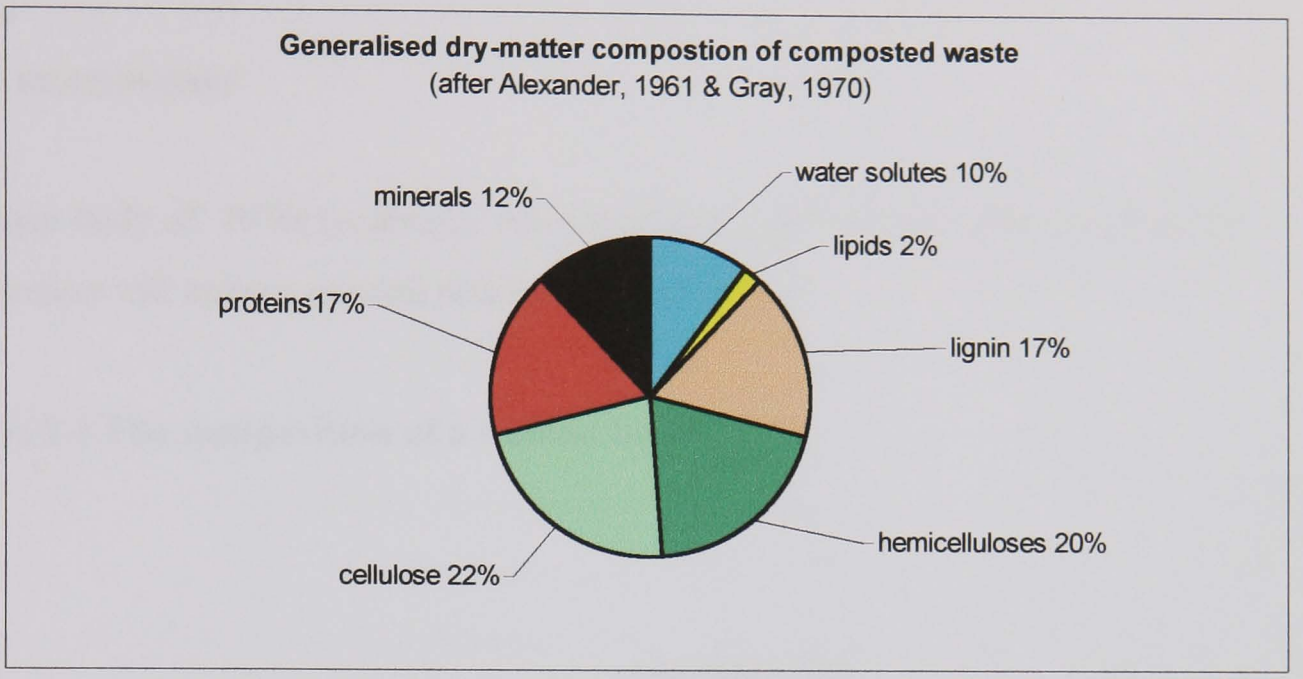
As stated above, the process of composting is an oxidative one and, as the vast bulk of manure consists of organic matter, major products are carbon dioxide and water, most of which is lost to the system.



A large part of the compost is water and although the process of digestion generates more water most compost heaps are free draining. There is little point, therefore, in

attempting to quantify the water content of the average compost. However, some attempts have been made to define the dry matter constituents of composted manure (see Figure 2.3 and Table 2.4).

Figure 2.3 **Composition of compost**



The following table demonstrates the variability that is to be expected in the composition of composted domestic waste.

Table 2.4 **Variability in composition of dry-matter in composted waste**
(after Gray *et al* 1974)

FRACTION		DRY WEIGHT (%)	
		minimum	maximum
SOLUBLE ORGANIC COMPOUNDS	sugars, starches, amino acids, urea, etc	2	20
LIPIDS	fats, oils, waxes & resins	1	3
PROTEINS		5	30
HEMICELLULOSES		15	25
CELLULOSES		15	30
LIGNIN		10	25
MINERALS (ASH)		5	20

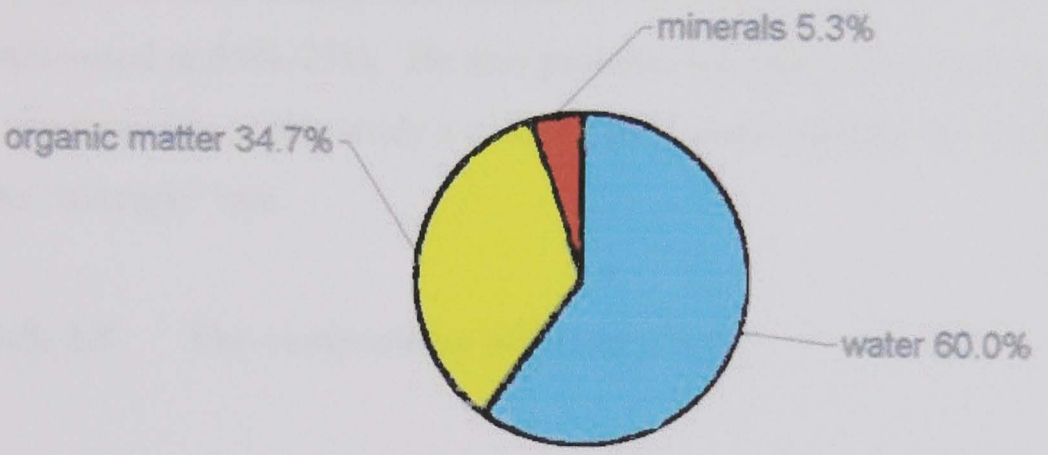
Composted domestic waste is rich in plant nutrients (minerals) and partially decomposed organic material. The former include fractions of nitrogen potassium and phosphorus but the minerals also include small quantities of heavy metals. The latter, like naturally occurring humus, adds structure to the soil (thereby improving aeration)

and a balance to water retention and drainage. A compost-enhanced soil will also encourage the continued activity of soil organisms providing thereby a slow release of further plant nutrients. In time much of the organic matter will be lost and only resistant residue (organic and inorganic) will remain.

2.2.4 DEAD BODIES

A human body of 70 kg (reference man) will have a dry weight of 28 kg which on combustion will leave a mineral residue (ash) of 3.7 kg.

Figure 2.4 The composition of a human body.



The major elements within the body are, of course, carbon, hydrogen and oxygen of which the bulk of the soft tissue, sugars and fat is composed. These are followed by sodium, chlorine, potassium, calcium, fluorine, magnesium, nitrogen, phosphorus and sulphur which make up the skeleton, body electrolytes and various other bio-chemical agents. Among the many other less abundant but, nonetheless, important body elements are iron (in the liver and red blood cells), copper, zinc, lead, aluminium, cadmium, rubidium and silicon. Lead is of particular note as ingested lead solutes, along with certain other of the heavier metals, accumulate in the bone tissue. In past periods (e.g. Roman and medieval) when lead and pewter ware, leaded water cisterns were widely used, food stuffs (particularly wine and ale) were often contaminated with lead. High lead-bone residues were not uncommon. Lead salts were also taken medicinally or deliberately added to foodstuffs and drink as preservatives or flavour enhancers. Oxides

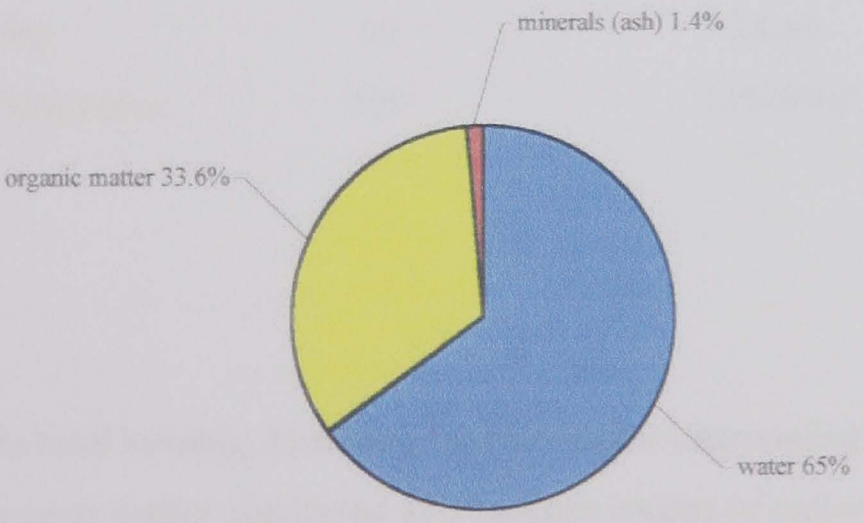
of lead were also used for paint, e.g. white lead paint and "Pompeian Red" paint. All these sources have contributed in the past to lead contamination of the bones of civilised peoples and not infrequently to their death through *plumbism*. (See Gilfilan, 1965)

In terms of inorganic soil residues it will matter little whether the body is buried or burned, although cremation would destroy any potentially long term soil- surviving lipids.

2.2.5 WOOD AND WOOD ASH

The composition of living wood has not been subjected to many systematic analyses. Much of the information on deciduous trees[21] is derived from cultivated orchard species and even here data on fresh weights are generally lacking. A study on conifers (Smith, 1971, 142) estimates that 50% of heart-wood and almost 100% of sap-wood is composed of water, the same proportions differentiating the inner and the outer bark. Smith quotes other evaluations (Kurucz, 1969) which put the water content of large branch-wood at 65%-75%. He also provides his own figure of 63% for the Douglas Fir. For the purposes of this study a value of 65% water content has been chosen as typical of the "average" tree.

Figure 2.5 The composition of living wood



Of the other 35%, most (96% of the dry weight, 33.6% of wet weight) is made up of organic hydro-carbons, e.g. lignin, cellulose, hemicelluloses, saccharides, starch, waxes and other lipids, etc. These are organic molecules and therefore are mainly composed of

carbon, hydrogen, oxygen but also nitrogen and sulphur. All these elements are subject to natural environmental cycles and would not be expected to end up as long term residents in the soil. Nevertheless, some do (see Section 2.4). Half of the remaining dry matter (2% dry weight or 0.7% wet weight) is made up of the elements chlorine, potassium, calcium, magnesium, phosphorus and silicon. The remainder (2% dry weight or 0.7% wet weight) comprises of small amounts of scores of other (mostly metallic) elements amongst which feature lead, zinc, copper, cadmium, manganese, nickel, cobalt and chromium.

Table 2.5 Composition of dry wood

Element	*Concentration in one kilogram (DM) of wood* (after Bowen, 1975)	
	mean(mg)	*range (mg)*
Cadmium	0.25	0.02-2.4
Chromium	0.5	0.03-10
Cobalt	0.1	0.005-1
Copper	9	6 – 14
Lead	1	1 – 8
Manganese	250	17-600
Molybdenum	0.1	0.06-3
Nickel	1	1 -4
Zinc	40	34-68
Phosphorus	400	120-2000

On total burning, however, (not anaerobic charcoaling) water would lose and the organic matter converted into gaseous oxides of carbon and water vapour. There would be little left but the mineral ash. This small component of fresh wood would accumulate in a concentrated form in the hearth or on the bonfire site.

[21] The composition of coniferous trees is much the same although they may be richer in aluminium and poorer in copper, sodium, sulphur and zinc (Bowen, 1975, 94).

2.2.6 INDUSTRIAL SPOIL

For the purposes of this research (which concentrates on small rural communities) consideration will be given to an appropriate selection of industrial activities: small scale iron smelting, smithing, firing pottery and charcoal burning. In all these processes those factors that bear most on soil changes are, the fuel for the kiln, furnace or hearth; the effects of heat; the raw materials; and the waste residues left behind

Iron Smelting: Sources of iron ore are locally common. Carbonate ores, for example, occur as nodules in various Palaeozoic limestones, clays and shales, and can often be gathered in quantity from weathered surface soil. There is evidence of iron working (suspected mine pits and associated slag) from early British Iron Age sites (Shepherd, 1980). All such natural iron minerals, except those with a very high sulphur content[22] are suitable for smelting. The prehistoric process changed little until the middle ages. Broken-up ore was heated with charcoal, hopefully to a temperature that exceeded 1150^0 C, and the molten slag run off. The spongy mass ("bloom") of iron was extracted from the bottom of the furnace and beaten into shape. Liquefying the iron so that it could be cast required a furnace temperature of 1540^0 C which did not become possible until the 14th Century (Hawkes & Wooley, 1963) and never consistently achievable until the 19th Century. The sophistication of pre-roasting the ore before full smelting was not practised in Europe until the 15th Century. As to the residues associated with iron smelting, apart from the burned clay fragments of the furnace wall and the fire hardened slag-filled hearth, there was the spoil, i.e. the discarded slag. Iron slag is largely iron silicate with small amounts of other elements such as calcium, potassium, sodium, magnesium, manganese, phosphorus and sulphur. These, being contained within a glassy matrix, are largely insoluble. However, fuel ashes probably contribute most to the soil contaminants as such large quantities of charcoal[23] were consumed in producing the metal. The residues of burned charcoal will be similar to wood ash (see above).

Smithing: The first function of the smith is not just to beat the "bloom" in to shape but to work the metal so as to remove as much of the retained slag (up to 20% of the unworked iron) as possible. As the worked iron cools it becomes more difficult to expel the slag so reheating in the charcoal-fired forge becomes necessary. The expelled material falls to the ground as globules of molten (non-magnetic) *hammer-slag*, or small plate-like flakes of (magnetic) *hammer-scale*. The archaeological evidence for smithing

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[22] Sulphur in iron makes the metal more brittle and sulphur contents greater than 1% can significantly affect the smithing quality.

[23] Approximately four tonnes of charcoal ($1000m^2$ of oak woodland) are needed to produce one tonne of iron (a re-calculation of figures in Healy, 1978, 151-152).

is often the fused slag filling the hearth bottom (often not easily distinguishable from a smelting hearth), the surrounding hammer slag/scale debris and burned clay. Again a major soil marker will be the residues from the relatively large quantities of wood and charcoal burned.

Firing pottery: Before the advent of kilns pots were fired in bonfires (Tylecote, 1987, 25) as they still are in some places in Africa. Nevertheless the earliest known (pre-historic) evidence of *pyrotechnology* is the pottery kiln which is simply a draught furnace with, eventually, the sophistication of a separate fire-box. Temperatures rarely reached more than 1000^0 C. Wood and charcoal were the main fuel sources.

Charcoal burning: Despite Marco Polo's recorded amazement at the end of the 13th Century, the oriental *black stone that burned* was no new discovery. Coal had been mined in Britain, for example, a thousand years earlier and has probably been used as an opportunistic fuel since prehistoric times (Shepherd, 1980, 232). The problem with coal was that it was not as abundant as wood and its high sulphur content made it unsuitable on the cooking hearth or in the furnace[24]. Wood for the fire and charcoal for the kiln was the common practice from the pre-historic period until the industrial revolution[25] . Nevertheless, although relatively abundant, any large scale industry risked creating its own local shortages. Transportation of large quantities of charcoal had its own logistical problems as well. As a consequence, from the Iron Age on, smiths either became itinerant or industries were sited near a sustainable source of fuel and the raw materials imported (Tylecote, 1987, 13). As a fuel, the water, carbohydrate and volatile components of wood prevent it from reaching temperatures sufficient to complete various industrial processes. But when cooked or slowed-burned buried in a pit (as late as the 16th Century – Rackham, 1986, 357) or in an earth-covered stack, the carbohydrates (chiefly lignin and cellulose) break down and the water and volatiles are driven off. The resulting charcoal (apart from the small component of mineral ash) is almost pure carbon.

Charcoal, which was used for smelting and forging iron, firing pottery and many other pyrotechnical processes, can burn at twice the temperature of a wood fire and, with the assistance of bellows, even higher. The carbon is almost entirely oxidised leaving behind a gradually accumulating residue of mineral ash (see above).

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[24] The high sulphur content of coal not only produced unpleasant fumes and tainted food, it contaminated smelted iron rendering it brittle and unworkable.

[25] Abraham Darby in Coalbrookdale at the beginning of the 18th Century finally introduced sulphur-free coke into the iron industry. Coal mining burgeoned and coal as a domestic fuel became plentiful and (relatively) cheap.

SECTION 2.3 QUANTIFYING THE PRODUCTION OF ANTHROPOGENIC SOIL DEPOSITS

The preceding two Sections have described the processes by which anthropogenic deposits are generated and examined their general composition. This Section will attempt to evaluate the quantity of such deposits that might accumulate in and around a small rural settlement over a period of time. It is emphasised that these evaluations are directed primarily at the immediate farmstead environs and not the outlying fields that surround it, although the affects of wider dispersal (manuring) will be taken in to account.

Before presenting the evaluation of an archetypal farmstead consideration is given to previous work on the subject, most notably that by three American researchers; S. F. Cook & R. F. Heizer in the mid 1960s and R. C. Eidt in the mid 1980s.

2.3.1 COOK AND HEIZER

In 1965 two researchers (Cook & Heizer) at the University of California conducted a study of ancient native American settlement sites in California and in Mexico. Their initial premise was that chemical changes in the soil can occur as a direct result of human activity or occupation, i.e. there is an accumulation of enriched deposits and that the discovery of such accumulations are presumptive of past human occupation or activity. The work was stimulated by Olaf Arrhenius (see Section 2.6), the pioneer of archaeological phosphate analysis, who was, at that time, visiting the university.

In the context of the study, the authors constructed a hypothetical community of a fixed size; occupying a defined area; and consuming, excreting and discarding at a set rate over a prescribed period of time. The quantity and quality of human and animal excreta was evaluated by the authors in two ways. First by the indirect analysis of observed volumes of excreta and body content, and secondly by the direct study of nutritional balances. The authors also considered intake data, based on standard maintenance requirements, to be relevant.

The presentation suffered somewhat from the of mixing units of measurement and by the adoption of broad generalisations. Some of the tables below are modified versions

of those of Cook & Heizer and others have been introduced for purposes of clarification.

A start is made with a hypothetical standard population (see Tables 2.6 & 2.7).

Table 2.6 Hypothetical standard population (after Cook & Heizer).

100 persons divided into three groups; adult males, adult females and children.

Average body weight:	Males	70 kg
	Females	50 kg
	Children	35 kg
Total body weight of the community		5162 kg

Table 2.7 Excretion by the community per day *(based on a generalisation of estimates made by Bell, Davidson and Scarborough, 1961).*

faeces	7.38 kilograms
urine	110.70 litres or kilograms

This equates to 1.4 3 kg of faeces and 21.5 litres of urine / 1000 kg body weight / day. Similar estimations have also been made for livestock (see Thorne 1941 & Van Slyke 1932) and these calculations have been put together with those of Bell *et al* (see Table 2.8).

Table 2.8 Daily output of faeces and urine (kg per 1000 kg body weight)

Animal	*Faeces*	*Urine*	*Total*
human	1.4	21.5	22.9
horse	39.3	9.9	49.2
cow	52.0	21.9	73.9
sheep	22.7	11.5	34.2
pig	50.0	33.3	83.3
hen	*	*	20.5

After Cook & Heizer, 1965 (after Bell *et al* 1961, Thorne 1941 & Van Slyke 1932)

The data as presented illustrate the dietary influence on faecal production, but would suggest humans are disproportionately prolific producers of urine. It should be noted, however, that 1000 kilograms of body weight might represent as many as 20 people but only 4 horses. So, bladder for bladder, horses are well ahead.

Cook and Heizer drew attention to the disparity in the weight of faeces production between man and animal. This was put down to dietary effects. Herbivores such as cattle, the authors argued, consume daily an enormous bulk of grass[26] yielding faeces with a high water content. This was not the case with humans. On the other hand, hens are very economical in their use of water and being largely graminiverous (particularly in domestication), tend to eat the dry parts of plants such as seeds and grains. Hence it is not surprising that their excreta production is less per body weight than other farmstead livestock.

Cook and Heizer equated urine production in humans with the other producers by averaging the combined output of all those mammals listed, i.e. 19.62 kg per 1000 kg body weight. This, they argued (rather tenuously), was evidence for an equivalence in the mammalian renal system.

The authors also looked at the composition of excreta, concentrating, as this research does, on nitrogen and phosphorus (see Table 2.9 and 2.10).

Table 2.9 Daily output of nitrogen, phosphorus and calcium in human beings

element	proportion of faeces	proportion of urine	Total (g per 1000 kg body wt.)
nitrogen	1.5 %	2.1%	471.8
phosphorus	0.06 %	0.12%	38.6
calcium	*not given*	0.015%	3.31

NB. In humans, 64-67% of excreted phosphorus is in the urine (Hawk, Oser & Summerson, 1954) but with animals most is in the faeces[27].

Table 2.10 Daily output of nitrogen and phosphorus in domesticated livestock (g per 1000 kg body weight)

element	cattle	sheep	hen
nitrogen	283.3	341.7	211.6
phosphorus	93.7	134.5	122.4
calcium	*not given*	*not given*	*not given*

The authors do not offer any explanation for the comparatively high output of nitrogen by humans. If this elevation is linked, as it probably is, to the consumption of meat then such output might not be consistent with ancient diets, except at specific times of abundance.

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[26] Conspicuous consumption of grass by domestic cattle is a feature of modern farming and is dependent on high-input grassland production. In the past cattle were often foragers on marginal grazing land and at the forest edge. Faeces production at those times would have been less prolific even if higher in fibre.

[27] Only 1% of phosphorus excreted by cattle occurs in the urine (Lofgreen, Kleiber and Luick, 1952).

Cook and Heizer also produced data on nutritional turnover from a number of sources (see Table 2.11).

Table 2.11 Daily output of nitrogen, phosphorus and calcium in adult male (70 kg)

element	Daily input (g) per adult male	Daily output (g) per adult male	Daily output (g) per 1000 kg body weight
nitrogen	12.0	14.5	207.9
phosphorus	1.2	2.5	35.9
calcium	0.8	0.9	12.8

Unfortunately, the assembled data derived from, a) measuring actual quantities of nitrogen, phosphorus and calcium in observed volumes of faeces and urine; b) estimating the daily turnover rate (nutritional balance) of nitrogen, phosphorus and calcium, and finally c) from considering minimal maintenance[28] requirements, do not always match (see Table 2.12).

Table 2.12 Daily output and minimal maintenance input of nitrogen, phosphorus and calcium in humans and in domesticated livestock (g per 1000 kg body weight).

element	Mean output (g) in observed volumes of urine and faeces in an adult human male	Direct determination of losses (g) by excretion in an adult human male	Minimum maintenance intake in an adult human male	Mean output(g) in observed volumes of urine and faeces in domestic animals
nitrogen	472	207	221	280
phosphorus	39	36	22	117
calcium	3	13	14	*not given*

Cook and Heizer then stated, " These data present certain very obvious discrepancies. The is little purpose, however, in attempting either to explain them or to eliminate them". The justification for this was that the authors sought an *order of magnitude*, not an *exact value*. The following approximated values were offered (see Table 2.13).

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[28] It would be reasonable to assume that minimal maintenance requirements of an adult would match any natural loss.

Table 2.13 Approximate contribution to the occupational substrate by man and animals (g per 1000 kg body weight per day)

element	Approximated daily output
nitrogen	220 g
phosphorus	33 g
calcium	13 g

The above was then translated into annual output per community i.e. per 100 individuals (see Table 2.14)

Table 2.14 Approximate annual contribution by excreta to the occupational substrate by a standard community of 100 individuals.

element	Approximated annual output
nitrogen	415 kg
phosphorus	62 kg
calcium	25 kg

Cook and Heizer considered other organic deposits, such as dead bodies (see Table 2.15) but were rather casual in their assessment of other waste material (see comments below). An assumption was adopted that dead bodies were usually buried whereas those of animals were generally not. If there were any implications[29] consequent on these assumed differences they were not elaborated upon.

The following table attempts to evaluate contributions from ***dead bodies***.

Table 2.15 Approximate contribution from dead bodies of nitrogen, phosphorus and calcium per annum from a community of 100 people (3% death rate)

element	Percentage composition	Annual contribution
nitrogen	3.0 %	4.5 kg
phosphorus	1.0 %	1.5 kg
calcium	1.8 %	2.7 kg

It can be seen that these quantities are relatively insignificant compared with the accumulations associated with excreta.

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[29] In principle there is little difference, in terms of metals or phosphorus recycling, whether the body, be it animal or human, is buried, abandoned or burned. Only how the remains are dispersed will effect the localised concentration of these elements.

Waste material was defined by Cook and Heizer as including food residues, particularly bones; other non-food animal and plant matter, including building materials; clothing and industrial residues, *"... not to speak of accumulation of ash from domestic fires"*. Note: it was shown in Section 2.2 that ashes, in fact, make a major contribution to detectable human residues and their contribution to accumulated human deposits is not to be underestimated. In their search for an empirical *order of magnitude*, Cook and Heizer made the (arbitrary) claim that soil residues from domestic waste were equal to that from excreta. They came at last to the following conclusion (see Table 2.16).

Table 2.16 Approximate total annual contribution (excreta and other waste) to the occupational substrate by a standard community of 100 individuals.

Element	Annual contribution
nitrogen	840 kg
phosphorus	124 kg
calcium	55 kg

Having dealt with the quantity and quality of the output, Cook and Heizer went on to consider (1) the area of contamination, and (2) the natural background levels of the contaminants. These factors will be discussed in subsequent Sections.

2.3.2. EIDT

In the 1980s, Robert Eidt, drawing to some extent on Cook and Heizer's earlier work made his own estimates (Eidt, 1984) of qualitative and quantitative changes to the soil that are brought about by past human activity. In this case, Eidt's interest was specifically soil ***phosphorus***, and by his calculation human adults excreted 2.5 g of phosphorus each day. Between 60% - 80% of this phosphorus occurred in the urine and 20% - 40% in the faeces.

In a community of ten families (25 adults and 25 children), Eidt estimated that 93.8 g would be excreted daily. He conceded that further soil phosphorus would be contributed by other domestic waste (although no particular mention is made of wood ash). His "conservative estimate" was (*a la* Cook & Heizer) that this would double the excreta figure, i.e. 187.6 g per day for a ten family community.

Eidt illustrated the daily accumulation of soil phosphorus by considering a small rural settlement consisting of these ten families within a living zone of 0.1 ha, with a surrounding cropping area of 100 ha, plus 100 ha of grazing land that supported 100 head of cattle (see Table 2.17).

Table 2.17 Daily changes in soil phosphorus per square metre on a small farm settlement.

Source	Phosphorus
50 people (body waste and garbage)	+ 187.6 mg
100 beef cattle (faeces and urine)	+ 4.2 mg
Crops (normal uptake, one crop/year)	- 0.04 mg

Although Eidt's archetypal farmstead is probably not typical of those considered in this thesis, and (by his own admission) his computations fairly arbitrary, we are talking about a community that will add several kilograms of phosphorus to the soil in every generation.

2.3.3 ASTON, MARTIN AND JACKSON

On the basis of the research carried out in the masters degree that preceded the present study, papers were published (Aston *et al*, 1998 a & b) in which calculations similar to those of Cook, Heizer and Eidt appeared. These are presented here to illustrate the continuity of approach and as the basis for evolving a theoretical archetypal settlement appropriate to this investigation.

The first set of calculations presented (see Table 2.18) show the relative effect of ***human faecal*** material on soil elemental composition. The calculations were *ad hoc* and based on a nominal family of 10 adults over a period of 100 years of occupation. They show the relative enrichment of soils based on average concentrations in 'normal' soils and also enrichment relative to the lowest concentrations of each element recorded from soils (based on over 1000 samples) taken from the wider landscape surrounding the site of investigation at Shapwick in Somerset.

The second set of calculations (see Table 2.19) show the concentrations of metals in ***wood*** that would remain in the ashes of cooking fires, bonfires, forges and furnaces and kilns. The type of wood is unspecified apart from being non-coniferous.

The results of these calculations are based on assumptions of a specific disturbance level from faeces enrichment or wood-ash enrichment. Using the enrichment values based on the lowest concentrations of elements found in Shapwick soil samples, for example, the calculations serve to emphasise which metals are likely to show the greatest anomaly from particular activities. In the case of enrichment from faecal material the order is

phosphorus>>cadmium>zinc>copper>molybdenum>lead>other metals.

For enrichment by burning of woody material the order is

phosphorus>>cadmium>manganese>zinc>>other metals.

This emphasises that these metals, phosphorus, cadmium, zinc, copper, lead, and manganese (and potentially molybdenum), can be anticipated to be those that could indicate anomalies in soil concentrations related to human settlement or activity. With

other activities, such as leather processing, metal working or burial, disturbances by additional elements may occur.

Table 2.18 **Input and enrichment values for soils based on input from human faeces. Calculations are based on the input of a family of 10 persons over a period of 100 years affecting an area of soil of 10 x 10 metres to a depth of 5 cm (using a bulk density of 1.3g/cm^3). Enrichment percentage values are based on median soil concentrations of the elements for normal soil (after Bowen, 1979), and on the lowest concentrations of each element recorded from Shapwick soil (based on over 1000 samples, except for phosphorus where over 500 samples, and cobalt based on over 250 samples).**

Element	*Faeces input g*	*Normal soil mg/kg*	*Shapwick soil * mg/kg*	*Enrichment mg/kg soil*	*Enrichment % Normal soil*	*Enrichment % Shapwick lowest conc.*
Cadmium	18.25	0.35	0.05	2.8	800	5600
Chromium	29.2	70	9.8	4.5	6.4	46
Cobalt	32.85	8	9.2	5.1	64	55
Copper	1241	30	30.6	190.9	636	624
Lead	109.5	10	25.3	16.9	169	67
Manganese	1314	500	315	202	40.4	64
Molybdenum	43.8	1.2	#	6.7	558	#
Nickel	135	50	16.3	20.8	41.6	128
Zinc	4020	90	71.9	618.5	687	860
Phosphorus	182500	650	160	28077	4319	17548

*** lowest concentration : # no data available for Shapwick soils.**

Table 2.19 **Concentrations of certain elements in angiospermous (non-coniferous) wood (* range data for wood and concentration in normal soil after Bowen 1979), and calculations of potential enrichment of a normal soil and Shapwick soil. The calculations are based on burning of 1000kg wood/year on soil for 100 years in an area 10x10 metre, affected to a depth of 10cm; (soil bulk density assumed at 1.3 g/cm^3). ** ratio of Enrichment to lowest soil concentration recorded from Shapwick.**

Element	*Concentration in Wood * mg/kg mean (range)*	*Concentration in Soil * mg/kg mean*	*Addition per unit area g*	*Enrichment mg/kg*	*Enrichment Normal soil %*	*Enrichment Shapwick lowest** %*
Cadmium	0.25 (0.02-2.4)	0.35	25	1.92	549	3840
Chromium	0.5 (0.03-10)	70	50	3.85	6	39
Cobalt	0.1 (0.005-1)	8	10	0.77	10	8
Copper	9 (6 - 14)	30	900	69.2	230	13
Lead	1 (1 - 8)	10	100	7.69	77	30
Manganese	250 (17-600)	500	25000	1923	385	611
Molybdenum	0.1 (0.06-3)	1.2	10	0.77	64	#
Nickel	1 (1 -4)	50	100	7.69	15	47
Zinc	40 (34-68)	90	4000	307.7	342	428
Phosphorus	400 (120-2000)	650	200000	153846	23669	96151

2.3.4 THE ARCHETYPAL FARMSTEAD

The main purpose of this Section is to evaluate the amount of measurable residues that are likely to accumulate in the soil as a consequence of past human activities. It is intended now to construct a theoretical archetypal settlement appropriate to the investigations undertaken[30].

A. The farmstead occupants:

Table 2.20 presents, it is suggested, the typical occupants of small farmstead, consisting of a localised concentration of animals and people. It is the hypothetical nucleus of a farm and might represent a primitive subsistence system or the core of a larger intensive or extensive farming practice[31]. It is argued that such small farming units are not atypical of parts of Europe from the Bronze Age almost to the present day.

Table 2.20 The farmstead occupants

Units	Comments
5 adult males 4 adult females 5 children	(grandfather, father, two sons, son-in-law, grandmother, mother, unmarried daughter, daughter-in-law)
4 cattle 12 sheep 2 pigs 20 chickens	two draft oxen; two milking cows – all stalled at least overnight penned overnight penned for farrowing or just overnight ranging around the farmyard.

The figures presented below (see Table 2.21) are by necessity very generalised and serve only to illustrate typical production of excreta. Although based on modern-day measurements, the weights for animals, for example, have been chosen from breeds that most approximate those used in the past. Horses have been left out because they were never an important part of ancient small scale farming.

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[30] The studies undertaken include several small farmsteads (Roman, and early medieval). See Part 4.

[31] The farming unit described might well support a nucleus of livestock plus a kitchen garden or toft providing its own immediate subsistence needs or maybe even extras (e.g. cheese, cream, vegetables, fruit etc), but at the same time be part of a wider and larger communal system (e.g. extensive cattle or sheep farming, woodland pig herding, open field cropping etc. (see Francis Pryor, 1998 – *Farmers in Prehistoric Britain, pp 105 - 108*).

Table 2.21 Typical body weights

Species	*Weight*
adult human male	70 kg
adult human female	58 kg
human child (over 5)	32 kg
cattle	300 kg
sheep	40 kg
pig	70 kg
hen	1.5 kg

Adult human body weights are taken from Snyder *et al* (1975 ,13) which approximate fairy well those given by Cook & Heizer (see Table 2.6). A generalised body weight for children is taken as a half the mean weight of a man and woman, although this is probably an underestimate (Altman & Dittmer, 1968, 344).

Estimates for cattle have taken the weights of a modern year-old shorthorn (350 kg) to represent oxen[32] and those of a modern year-old Jersey (250 kg) to equate with older breeds of milking cows (calculated from Altman & Dittmer, 1968, 346 & 548) . For the purposes of this calculation the mean weight of these combined breeds is adopted.

Sheep were also smaller in the past than they are today and although often, as wool producers and milking animals, surviving well into maturity, the weight taken here approximates that of a modern yearling (40 kg).

How big is a pig? As rapidly maturing animals and being exploited for their fat as well as their meat, many would have been slaughtered at early stage[33]. Life expectancy would have been greater for the boar and the breeding sow, both of which (certainly the latter) were probably penned on the farmstead. Pigs were never as intensively farmed as they are today. The weight chosen is about half that of a modern year-old gilt (70 kg).

The weight of a modern domestic hen is about 1.8 –2.5 kg (Altman & Dittmer, 1968, 103). Again allowing for increased body weight due to breed improvement (perhaps not as dramatic as for other livestock) a weight of 1.5 kg has been taken.

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[32] Iron Age and Roman oxen were small (possibly half the size) in comparison with those in use from the 16th Century on. (Sweeney, 1995,53).

[33] The Romans had a weakness for "suckling pig" (Jones & Dimbleby, 1981, 183).

B. The deposits generated:

The following table (Table 2.22) is a modified version of that present by Cook and Heizer[34].

Table 2.22 Daily output of faeces and urine (kg per 1000 kg body weight)

Animal	Faeces	Urine	Total
human	6.3	21.5	27.8
cow	52.0	21.9	73.9
sheep	22.7	11.5	34.2
pig	50.0	33.3	83.3
hen	*	*	20.5

The output for all these categories is based on modern diets and is probably (certainly in the case of cattle) an overestimate of past production. Nevertheless, faecal and urinary output is a factor of diet and diets of people and animals will have been different in different time periods. This being the case any adjustment would be arbitrary. Nevertheless this factor will be taken into account when summing up.

Some comment is required on the faecal output of humans. Cook and Heizer put this at **1.4 kg per 1000 kg body weight** and commented (see above) on the very obvious disparity between this and typical outputs of domestic livestock, e.g. the pig producing thirty six times the amount of faeces that humans do (kg per 1000kg body weight). The authors could suggest no explanation other than diet and appetite. However, Snyder *et al* (1975, 352) Reference Man produces, as an individual, 135 g faeces per day, reaching 500g for a purely vegetarian diet. As past diets would have probably had a much higher plant content[35] a figure of 400 g faeces per day is chosen. Taking the weight of Reference Man (male & female) at 64 kg, faecal output for humans works out, in fact, at **6.3 kg per 1000 kg body weight**. This is four and a half times as much as Cook & Heizer's estimate.

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[34] From Cook and Heizer, 1965 who based it on data from Bell, Davidson and Scarborough 1961, Thorne 1941 & Van Slyke 1932).

[35] There were, of course, exceptions to the predominantly vegetarian diet, such as on special feasting occasions or where food production from arable agriculture was minimal or non-existent (e.g. Mesolithic littoral hunter gatherers, Inuit Indians etc)

Nevertheless, there still remains a marked discrepancy between humans and domestic animals which may indeed be dietary but must also reflect the relative (to the diet) efficiency of human digestion.

Combining the above information the following output for the hypothetical community can be derived (see Table 2.23).

Table 2.23 Daily output of faeces and urine per group

Animal	body weight	Faeces	Urine	Total
14 humans	742 kg	4.7 kg	16 kg	20.7 kg
4 cattle	1200 kg	62.4 kg	26.3 kg	88.7 kg
12 sheep	480 kg	10.9 kg	5.5 kg	16.4 kg
2 pigs	140 kg	7.0 kg	1.6 kg	8.6 kg
20 hens	30 kg	0.3 kg*	0.3 kg*	0.6 kg
TOTAL		85 kg	49.4 kg	135.0 kg

*Birds excrete uric acid crystals with the faeces through the cloaca. Consequently there is no distinction made here between faeces and urine.

This equates to an annual farmstead output of excreta of approximately 50 tonnes.

If we now go on to consider the consumption of wood as a fuel by the inhabitants of our farmstead for cooking, heating, disposing, forging and firing, the following estimates of usage are suggested

It is likely that a ***cooking fire*** (like the farmhouse ranges I grew up with as a child) was kept burning continuously although, when not needed for cooking (e.g. bread) or heating, it would have been allowed to smoulder on a minimal amount of fuel. From my own experience, a closed range could consume between five and seven tonnes of wood in a year, depending on how long any cold weather lasted. A more open hearth would use a bit more, probably up to ten tonnes of wood a year. Nine tonnes per year would equate to about 25 kg of wood per day.

A ***bonfire*** would be a much more infrequent event and probably, as tradition still dictates, a post harvest occurrence in which the large bones of winter-killed livestock were disposed of. This might also have been combined with some sort of celebration and, as such, could have been a cross-community event taking place away from the farmstead. This is, of course, pure speculation and any estimate of the amount of wood or equivalent burnable matter used would be totally arbitrary. Undaunted, it is suggested such a seasonal event occurring close to the farm might consume the

equivalent of less than a quarter of a tonne of wood. Interpreted on a daily basis this equates to about half a kilogram.

A community as small as is considered here, unless too remote to obtain any external supply, would not in all likelihood smelt its own iron. It might, however, indulge in some smithying. It might also make and fire its own pots. It requires 4 tonnes of charcoal (16 tonnes of wood) to produce a tonne of iron. It is estimated that to fuel a ***forge*** and ***pottery kiln***, even if only used as occasion demanded, almost one tonne of charcoal (up to 4 tonnes of wood) could be used each year. This would be equivalent to approximately 10 kg per day (see Table 2.24).

Table 2.24 Daily consumption of wood per group

cooking fire	*bonfire*	*forge, kiln etc*	*Total*
25 kg	0.25 kg	10 kg	35.25 kg

Having already discussed three major sources of anthropogenic deposits (human excreta, livestock excreta and ashes) there remains other domestic waste; waste food, waste animal matter (bone, offal, feathers) and waste or deliberately gathered plant material. Cook and Heizer (1965, 8) in estimating the quantity of domestic waste other than excreta (but including ashes) simply gave it an equivalent value, i.e. the total amount of referable waste equals that for human and animal excreta times two. Rather than stretch conjecture beyond reasonable limits in attempting any refinement on this estimate consideration of the contribution of other domestic waste will be deferred for the moment.

At this point mention is made of ***negative contributors*** to anthropogenic deposits in and close to the farmstead, i.e. the removal of human deposits as manure to be spread on outlying fields and the disposal of dead bodies for burial. The removal of manure, could significantly reduce on-site contamination and this will have to be factored into any final calculation. Dead bodies, however, are to be omitted from this calculation One or two dead bodies every ten years, for example, would make little contribution to the overall pool of accumulating deposits, although over generations a family cemetery would concentrate these residues and probably leave measurable traces. For the purposes of this study, however, it is being assumed that the dead are removed altogether from the site for cremation or inhumation at some special place.

C. Measurable indicators:

The next Section examines the fate and survival of anthropogenic residues and, as will be demonstrated, concentrates on surviving organic molecules and inorganic elements. It is appropriate here to quantify these measurable indicators of past human activity.

All organic material will eventually be oxidised and produce water and carbon dioxide. Some organic material may survive for a considerable time as stable molecules (e.g. lipids) or become mineralised carbon (e.g. lignite or coal). Quantifying precisely how much organic matter will survive and for how long is not easy (see Section 2.4). Better estimates might be made for inorganic elements.

Thirteen percent of **human faeces** is mineral, mostly chlorine, sodium, potassium, sulphur, phosphorus, calcium and magnesium, but includes small quantities of the heavy metals cobalt, copper, lead, manganese, nickel and zinc. Slightly over four per cent of human urine is mineral. The constituents are similar but the balance is different. Urine contains most of the nitrogen and a large proportion of the chlorine, sodium and potassium. A larger proportion of the heavy metals occur in the faeces (see Table 2.25) with the exception of lead and, to some extent iron.

Table 2.25 Mineral excretion (faeces and urine only) by humans (grams per day) – *after Snyder et al*

Element	Urine	Faeces	Total
Chlorine	4.40 g	0.05 g	4.45
Sodium	3.3	0.01	3.31
Potassium	2.8	0.36	3.16
Calcium	0.18	0.74	0.92
Magnesium	0.13	0.21	0.34
Nitrogen	15.0	1.5	16.5
Sulphur	0.8	0.14	0.94
Phosphorus	0.9	0.5	1.4
Cadmium	0.0001	0.00005	0.00015
Chromium	0.00007	0.00008	0.00015
Cobalt	0.0002	0.00009	0.00029
Copper	0.00005	0.0034	0.00345
Lead	0.000045	0.0003	0.000345
Manganese	0.00003	0.0036	0.00363
Nickel	0.000011	0.00037	0.00381
Zinc	0.0005	0.011	0.0115
Aluminium	0.001	0.043	0.044
Iron	0.00025	0.015	0.01525

The range and relative proportions of elements excreted by **livestock** is not dissimilar, although the quantities produced and the relative distribution between faeces and urine does, vary. The mineral content of dry **wood** is shown in Table 2.26.

Table 2.26 Mineral content of wood (grams per kg dry matter) –*after Bowen*.

Element	*Concentration in one kilogram (DM) of wood*	
	mean(mg)	*range (mg)*
Chlorine	*710*	700-720
Sodium	*492*	34-950
Potassium	*9.5*	4-15
Calcium	*8.5*	3-14
Magnesium	*5.2*	1.3-9
Nitrogen	1.4	-
Sulphur	*1900*	2000-1800
Phosphorus	400	120-2000
Cadmium	0.25	0.02-2.4
Chromium	0.5	0.03-10
Cobalt	0.1	0.005-1
Copper	9	6 – 14
Lead	1	1 – 8
Manganese	250	17-600
Molybdenum	0.1	0.06-3
Nickel	1	1 -4
Zinc	40	34-68
Phosphorus	400	120-2000
Aluminium	*125*	70-180
Iron	*145*	90-200

N.B. The figures in *italic* are median values of the range.

From the data above, it becomes possible to begin an approximate estimation of the quantity of mineral residues derived from organic deposits accumulating day by day on this archetypal farmstead (see Table 2.27).

Table 2.27 Daily generation of organic mineral deposits by an archetypal farmstead

source	**weight**	**minerals (%)**	**minerals (kg)**
human faeces	4.7 kg	13	0.282
human urine	16 kg	4.2	0.672
livestock faeces	80.3 kg	3	2.409
livestock urine	33.4	4	1.336
wood	35.25	1.4	0.494
other domestic waste	?	?	?
… minus manure removed			

The total weight of organic mineral deposits produced per day by the archetypal farmstead from quantifiable sources is 5.193 kg. This figure is an underestimate as it

does not account for **other domestic waste**. Cook and Heizer (specifically in terms of estimating nitrogen, phosphorus and calcium) guessed at a figure equivalent to that generated by human and livestock excreta. This would amount (less the wood ash already accounted for) to 4.7 kg. This is in my opinion a considerable overestimate. Subsistence societies do not waste anything with potential use. Waste food, offal, even chaff and leaves would most likely have been fed to the pigs and chickens. Rounding the total mineral deposit figure up to 6 kg per day would be a more intelligent guess.

The question now arises, as to how much of this waste material leaves the farmstead for the surrounding fields. It could be none; it is unlikely that it would be all. As far as inorganic minerals are concerned, a fraction would inevitably be carried into the soil beneath the manure heap or midden by draining water and soil organisms as the accumulated waste decomposed; a quantity would be retained in manure (or raw waste) thrown on to the kitchen garden; and a proportion would inevitably remain from gratuitous spillage, uncollected excreta, as well as blown ash and dust. Depending on the manuring practice adopted, anything between 0% and 80% of waste material may be removed from the immediate settlement area for dispersal on surrounding farm land.

The archetypal farmstead will produce between 1.2 kg and 6 kg of inorganic minerals per day. This equates to 438 kg to 2190 kg per year. In a generation (30 years) as much as 65 tonnes of mineral ash could accumulate.

One further step is usually taken to complete the quantification of anthropogenic deposits generated by the archetypal farmstead. As stated at the beginning of this Section, the investigations contained in this piece of research are directed at the immediate confines of settled community, in archaeological terms a *site area*, in essence, a search is being made for Bintliff's *halos* (Bintliff *et al*, 1990). How big, therefore, is the farmstead?

Cook & Heizer, after considering estimates made in their own earlier publications (and one other) arrive at two acres (0.81 ha) as the community living space for 100 persons. The above data were thereby converted to accumulation per year per unit area (see Table 2.28).

Table 2.28 Approximate total annual contribution (excreta and other waste) per hectare by a standard community of 100 individuals.

Element	Annual contribution per hectare
nitrogen	1037 kg
phosphorus	154 kg
calcium	68 kg

Cook & Heizer considered that most of these anthropogenic residues were to be found in the top 10 cm of the soil. The volume of soil for an occupation site was calculated at (810 m^3) with a weight of 1,215,000 kg. (Note: the authors had assumed a soil bulk density of 1.5 which is unrealistically high – 1.3 would have been high, but more acceptable.)

Using very generalised figures for average nitrogen, phosphorus and calcium content of soil, Cook & Heizer calculated that annual increases due to human occupation (see Table 2.29).

Table 2.29 Approximate annual increment to the soil by a standard community of 100 individuals.

Element	Increment
nitrogen	0.7 – 7.0 %
phosphorus	0.5 – 10.0 %
calcium	0.02 – 0.4 %

In terms of the archetypal farmstead, it is improbable that there is a linear correlation between the size of the site and the number of its occupants. Indeed our archetypal family of 14 might easily fill a couple of acres (0.81 ha) with their house, garden, barn, byre, pens and enclosures, taking up the equivalent space required by Cook & Heizer's settlement of a hundred Native Americans. Similar problems arise when considering the volume of soil that has been enriched by anthropogenic residues. Does one consider the top 5 cm, 10 cm, 30 cm or more? Quite clearly a whole range of factors (e.g. climate, water table, vegetation cover, earthworm population, the history of cultivation and cropping, soil pH, soil depth, subsequent burial of the archaeological layer, the physical and chemical character of the soil itself etc.) can have a bearing on the volumetric quantity of soil affected by anthropogenic residues and, in any absolute

sense, the choice of one or other would be arbitrary. There is, however, a reason why a choice might be made. For any objective assessment of soil contamination it is necessary to standardise sampling procedure and to use comparable units of measurement. All the samples in this investigation were taken to a depth of 15 cm and the reasons for this are discussed in Part 3. Purely to provide a unit of measurement, calculations in work preceding this study (Aston *et al*, 1998 a & b) were based on the input of a family of 10 persons over a period of 100 years affecting an area of soil of 10 x 10 metres to a depth of 5 cm (using a bulk density of $1.3g/cm^3$). The choice of such a standard of measurement, though reasoned, is ultimately a matter of convenience.

It has been calculated in this Section that our archetypal farmstead could in one generation accumulate as much as 65 tonnes of mineral deposits. That is, if it remained in the soil undisturbed and unchanged. What happens to anthropogenic deposits, be they inorganic or organic, is discussed in the next Section.

SECTION 2.4 THE FATE OF ANTHROPOGENIC RESIDUES

Whether anthropogenic deposits are derived from domestic or agricultural waste, from industrial processes, or even from building materials, most of what is generated is of organic origin and most of what eventually finds its way into the soil retains an (possibly less complex) organic form.. This Section will consider what happens to these organic deposits, and if and how any residues might survive to be detectable hundreds, if not thousands, of years later. There are other anthropogenic deposits such as elemental carbon (e.g. charcoal, soot etc), metallic oxides and salts, particles of metals and heat-altered clay debris (baked clay, daub, fragments of pottery, tile and brick), all of which are derived from high temperature processes. These are only briefly touched upon in this thesis.

2.4.1 RESIDUES DERIVED FROM ORGANIC DEBRIS

Consideration of the component elements of (decaying) plant material or animal (human) excreta reveals that they are dominated by carbon, hydrogen and oxygen with the electro-motive elements calcium, potassium, sodium and magnesium and the non-metals sulphur, phosphorus, chlorine and nitrogen making up the bulk of the rest. The heavier metals are a tiny proportion (less than 1%) of the total. The predominance of carbon, hydrogen and oxygen, being essential constituents of living organisms, is not surprising (see Table 2.30 & 2.31).

Table 2.30 Elemental composition of plant material (after Bowen, 1979)

Element	Mean percentages based on weight of dry matter
carbon	40
oxygen	39
hydrogen	5.0
silicon	4.0
nitrogen	3.5
potassium	3.0
calcium	1.3
magnesium	1.0
sulphur	1.0
phosphorus	0.3
chlorine	0.3
sodium	0.1
all the rest (inc. heavy metals)	1.5%

Table 2.31 Elemental composition of human excreta

element	daily excretion in urine and faeces (%)	daily excretion in urine and faeces (g)	comments
oxygen	86.4	1350	almost all as water in urine. similar amounts in exhalation plus sweat
hydrogen	10.5	167	
nitrogen	1.06	16.5	mostly in urine
carbon	0.77	12	most (270 g) is exhaled
chlorine	0.30	4.5	a further 1 g in sweat
sodium	0.20	3.5	a further 1 g in sweat
potassium	0.20	3.0	
phosphorus	0.10	1.5	
calcium	0.05	1.0	
sulphur	0.05	1.0	
magnesium	0.02	0.3	
all the rest (inc. heavy metals)	0.30	4.7	

Reference man excretes 135 g faeces and 1428 g urine per day. (Total 1563 g per day)

As will become clear, in terms of soil chemistry, it is convenient to group anthropogenic residues into four categories each containing compounds of either organic carbon, other non-metallic elements, electropositive metals and heavy metals.

A. ORGANIC CARBON

Almost all of the world's carbon is contained within carbonate minerals in the lithosphere or as carbonate/bicarbonate solutions in the worlds oceans. Free elemental carbon in an amorphous form or as graphite or diamond has been described (Butcher *et al*, 1992, 239) as a "curiosity". That part of the global carbon reservoir tied up in an organic cycle is tiny. Within this organic cycle the carbon exchange is dominated by that between living creatures and the atmosphere (including soil air)[36].

It can be seen in the tables above that most of the organic matter subjected to the metabolic actions of animals, plants or microbes, is excreted as carbon dioxide and water. These are the products of respiration or, if the organic matter is incompletely

[36] Carbonates within soil minerals are usually lost to the system in the leachate, but occasionally contribute to soil air as carbon dioxide.

utilised, as the oxidised products of decaying excreta or moribund tissue. Whether surviving for long periods as relatively soil-stable or geologically altered hydro-carbons (e.g. soil lipids, petroleum etc), as mineralised or elemental carbon (charcoal, lignite or coal) or as other gases (carbon monoxide, methane etc), the ultimate fate of all organic carbon is to revert to carbon dioxide. Carbon dioxide is returned to its organic form through the process of photosynthesis as part of the *biological carbon cycle*, although it is often over looked that this is only a sub-system of a *global carbon cycle*. Carbon dioxide is absorbed by the worlds oceans where it forms carbonate deposits (again with a contribution from a marine biological cycle). These sediments are eventually subsumed under continental plates by tectonic activity, the carbon dioxide finding its way back into the atmosphere through volcanic emissions. This process works on a geological timescale of millions of years. Our concern here, however, is that part of the biological carbon cycle encompassing the transition of dead, decayed or digested organic matter. These processes operate on a timescale ranging from days, even seconds, to hundreds if not thousands of years (Butcher *et al*, 1992, 239). It is the turn over of organic matter in the soil that is considered next.

THE TURNOVER OF ORGANIC MATTER IN THE SOIL

Globally, the amount of carbon in the top metre of soil is equivalent to that within the remainder of the terrestrial carbon cycle (i.e. green plants plus atmosphere). Except where there are exotic additions or major environmental changes[37] this equilibrium (within a very dynamic cycle) is maintained. It has been estimated (Wild, 1988, 588) that organic carbon is *turned over*, every 27 years. One might conclude from this that the element was an unsuitable indicator of past human activities. However, it will be demonstrated, that the turn over for some products of decay is longer term[38]. First it is necessary to look a little more closely at the constituents of soil organic matter.
Soil organic matter is a complex of living, dead and decaying organisms much of which is still recognisable for what it is, or was. It also includes the products of decay that have lost all traceable origin and are referred to generally as *humus*. The chemical composition of humus is still a matter of much investigation. Traditional extraction (alkali) techniques have produced fractions classed as humic acids, fulvic acids and humins. Other reagents (sodium pyrophosphate, formic acid, etc) can generate other

[37] The effects of burning fossil fuels, of clearing forests, of increases in the population of domestic herbivores and the application of synthetic fertilisers is discussed in the next section.
[38] Note also that the presence of organic matter facilitates the persistence of metallic elements (and phosphorus) in the soil. Even a turnover as short as twenty seven years will not destabilise these residues as long as the overall pool of bondable organic molecules does not diminish – see later.

fractions. Organic solvents have been used to remove lipids. Nevertheless, extractable fractions can only tell us a limited amount about the true composition of humus. It is known that humus contains free sugars, amino acids, organic acids and appreciable amounts (1% - 5% of soil carbon) of lipids. But it would appear that more complex molecules (polysaccharides, amino-sugars, amino acid polymers and organic compounds of phosphorus, sulphur and metals) are important, as well as what are euphemistically referred to as *humic substances*. Even the most modern research can only tell us that humic substances are a mysterious complex of polymerised hydrocarbons.

When plant material decomposes in the soil, it is the cellulose carbon that is released first and fairly quickly (50% in the first 30 days – Wild, 1988, 592) and taken up by soil microbes. Within months this process is complete. Lignin (an organic polymer itself) can only be broken down by a small group of aerobic microbes which explains why wood survives for considerable time periods in anaerobic conditions. Other organic polymers are similarly resistant to degradation[39], if not more so and can, in suitable conditions, accumulate indefinitely (Wild, 1988, 596).

It should also be noted that, apart from any intrinsic inertness or seemingly irreducible quality, some organic matter can achieve long term stability as aggregated colloids in soil water or form strong linkages with clay particles. In the latter situation, soil metals often act as bridging cations.

Long term studies at Rothamsted Experimental Station on arable fields have demonstrated that, when manuring is suspended, within a generation a residual equilibrium of soil organic matter is reached. Also that these fields still retained more organic carbon than un-manured fields, even a hundred years later (Wild, 1988, 591). Other work at the research station in the late 1970s (Jenkinson *et al,* 1977) demonstrated that the turnover of organic carbon was more complex than had been previously suggested and that there was a small but accumulating residue which is stable over centuries if not millennia. Data assembled from long-term manuring field trials were fitted to a model in which soil organic matter was separated into five theoretical compartments: decomposable plant matter (DPM half-life 0.165 years); resistant plant material (RPM, 2.31 years); soil biomass (BIO, 1.69 years); physically stabilised organic matter (POM, 49.5 years); and chemically stabilised organic matter (COM 1980 years). For a unitary input of plant material (1 t fresh plant C ha^{-1} $year^{-1}$) under steady state conditions, after 10,000 years, the model predicts that the soil will contain 0.01 t C in

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[39] "*The reason why the particular chemical and physical structures found in humified organic matter are resistant to microbial attack are still not fully understood.*" Wild, 1988, 602.

DPM, 0.47 t in RPM, 0.28 t in BIO, 11.3 t in POM and 12.2 t in COM. The predicted radiocarbon age is 1240 years (equivalent age). The fit between predicted and measured data was sufficiently good to suggest that the model was a realistic representation of the turnover of organic matter in cropped soils.

Accumulations of anthropogenic organic carbon are most likely associated with intensive and prolonged settlement, i.e. the occupational focus rather than the surrounding farmed land. It has been argued (Evershed *et al*, 1997) that changes in soil chemistry as the result of the manuring of farm land are short lived and that the measurement of specific elements such as carbon is unlikely to reveal enhancement over time. The same workers also argue that certain biological molecules (lipids), being among the slowly accumulating recalcitrant compounds, might have potential as *biomarkers* for human settlement or activities. But it is worth noting that soil lipid constitutes an appreciable amount of soil organic carbon (at least 1% - 5% - *see above* but can reach 42% of the total - Dinel, Schnitzer & Mehuys, 1990). Soil lipids can survive for millions of years and even become incorporated in sedimentary rocks (Wyckoff, 1972, Nes & Nes, 1980, Mackenzie *et al*, 1982).

Organic carbon, in some form or other, can indeed persist in the soil and residues from anthropogenic deposits can accumulate thereby leaving evidence of past human activity.

"DARK EARTH"

There is a widely held association of dark soils with sites of ancient human settlement. In rural situations this is witnessed by field names such as '*black lands*' which often contain archaeological evidence of abandoned (in many cases Roman) settlements. It has been shown that these darker soils are coincident with areas of enhanced organic carbon (losses on ignition) - see Aston *et al*, 1998[40] . In what were British cities layers of dark earth, sometimes several metres thick, have been found sandwiched between Roman urban ruin and Saxon resettlement. Macphail (1981) examined "dark earths" from Roman, Viking and medieval sites testing, among other things, for phosphorus, loss on ignition, soil pH, soil colour, and surviving plant remains. His general conclusions were that they were of a largely urban anthropogenic origin and either resulting from accumulations of domestic waste or dumped urban garden soil.

[40] The evaluation of organic carbon in the soil to determine evidence of human settlement has already been used by archaeologists with some success since the early 1960s (E.g. Mattingly & Williams, 1962; Cook & Heizer, 1965; Gardiner & Walsh, 1966; Griffith, 1980: Aston, Martin & Jackson, 1998a).

B. OTHER NON-METALLIC ELEMENTS

SULPHUR: Most soil sulphur is ultimately derived from the oxidation of sulphidic minerals in rocks particularly those sedimentary rocks of a marine origin. Appreciable amounts of sulphur arrive in rain fall deriving indirectly from industrial[41] and volcanic emissions. Within the soil, sulphur is present to a large extent as organic matter (in the tissue of living and dead organisms and in their decay products) in concentrations ranging from 200 – 2000 kg ha^{-1} (White, 1997, 204). This organic sulphur is eventually released by microbial action. The rate of this release is dependent on the carbon : sulphur ratio within these residues. The released ("mineralised") sulphate ions, unlike those say of phosphates, are only weakly adsorbed onto mineral surfaces and tends to stay in solution. Although thereby readily available as a plant nutrient this labile sulphur is also prone to leaching. Analysis (Williams, 1975) of soil water drainage from neutral and alkaline soils in southern England recorded losses of 78 kg – 100 kg of sulphates per hectare per year compared with 50 g – 130 g of phosphates.

CHLORINE: The chlorine present in most soils is deposited by rainfall and exists as simple chloride salts, as does that derived from anthropogenic residues. These chlorides, being anions, do not adsorb with any great strength on to clay particles. Existing to a great extent as soil-water solutes, chlorine is leached rapidly out of the soil and is not, consequently, a realistic candidate indicator of past human activity.

NITROGEN: Ninety per cent of the nitrogen on this planet is to be found in the atmosphere in its elemental form. Most of the rest exists as various compounds trapped within crustal sedimentary rocks (coal, oil, oleaginous shales etc). Unlike carbon dioxide, the world's oceans contain only a tiny fraction (0.5%) of the nitrogen inventory. Although the cycling of nitrogen largely takes place between the atmosphere and living organisms (mostly microbial), it is of note that terrestrial nitrogen (organic and inorganic nitrogen in soils, together with all that of land plants and animals) represents less than 0.01% of the total. (Butcher *et al*, 1992).

Considering faecal and urinary concentrations one might suspect that animals were the major source of organic soil nitrogen and indeed, on a small farmstead their contribution would be important. Nevertheless, terrestrial plant biomass holds much

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[41] Atmospheric pollution is discussed in section 2.5.3.

more (50 to 70 times –Butcher *et al*, 1992, 274) nitrogen than terrestrial animals. Through the various processes of decay much of this plant matter, faecal and urinary nitrogen passes to participating micro- and meso-organisms.

Any microbial action started in the compost heap or moribund tissue continues in the soil. Details of the action of these microbes in breaking down nitrogenous molecules ("denitrification") , in reconstructing plant available ions ("nitrification"), or, for that matter, in the fixation of atmospheric nitrogen (within leguminous plants) can be found in most biological text books and are not elaborated upon here. That there is a very active biological cycling of nitrogen is evident; what is important in this study is the persistence of anthropogenic nitrogen in the soil.

There is a biological balance between nitrogen and carbon in the soil which is, in simple terms, a reflection of the relative requirements for these elements by living organisms. Crop scientists are concerned with the availability of nitrogen as a crop plant nutrient. Only the labile forms of inorganic nitrogen are absorbable by plant roots. The amount of this free nitrogen relative to that bound up in (living and dead) soil organic matter has long been an object of intense study. This carbon : nitrogen ratio has a natural equilibrium (geographically different and determined by climate) which is disturbed by the addition of organic matter. When organic residues are added to the soil, microbial biomass increases as the decomposing sources of organic carbon are converted into microbial living tissue. At the same time, soil nitrogen is assimilated by the same microbial organisms and the carbon : nitrogen ratio increases rapidly[42] . When all the activity of the initial decomposition is completed the population of participating soil-organisms declines and the nitrogen is again released. The carbon : nitrogen ratio returns to an equilibrium.

If the purpose of our investigation is the evaluation of the total accumulation of anthropogenic soil nitrogen (be it organic or inorganic), plant nutrient requirements should be of little or no interest to the archaeologist. They might become so if the method of soil nitrogen assessment used by the archaeologist has been borrowed from the plant nutritionalists (see below).

Ninety to ninety five per cent of the nitrogen in the top soil exists as organic nitrogen (Wild, 1988, 653) mostly as amino compounds within living organisms. As illustrated

above, the exact amount depends on the prevalent carbon : nitrogen ratio. The remaining soil nitrogen is present as nitrate or ammonia ions, a proportion of which are adsorbed ("fixed") onto clay particles (often to a greater degree in the more-clay-rich subsoil). Only 1% - 2% of soil nitrogen (nitrate or ammonia ions) exists in solution (Brady, 1974, 423).

It should also be noted that when considering the contribution of anthropogenic residues to soil nitrogen, losses to the atmosphere of volatile gases (e.g. ammonia) during the process of decomposition will have an effect. How much is difficult to quantify as several variable factors (temperature, rainfall, humidity, composting procedure etc) influence the process. Note also that burned residues (ashes) would have lost all these volatile components.

The crucial reservoir of soil nitrogen is (living) organic matter. Nitrogen is lost from the soil by the leaching of soil water solutes, the escape of volatile ammonia and of nitrous oxide and nitrogen itself[43]. It follows that evidence of human activity in terms of soil nitrogen depends on the long term survival of soil organic matter. It is reasonable to assume that this will begin to diminish as soon as human activity ceases. What is not known is whether any proportion of that organic nitrogen is more resistant to decay than the rest, or if the small inorganic fraction that bonds with clay particles can persist sufficiently to provide detectable evidence.

Soil nitrogen estimations have been used by archaeologists in the past but few attempts have been made in recent years[44]. The American archaeologist Lutz (1951) made the association of elevated soil nitrogen levels with luxuriant plant growth on deserted ancient settlements in Alaska. These elevations in nitrogen were real but it has since been shown (Pigott & Taylor, 1964) that such plant growth is primarily due to enhanced levels of soil phosphorus. Mattingly and Williams (1962) examined soils in, under and around a Roman amphitheatre in Wiltshire. They used a fossilized carbon : nitrogen ratio as indicative of a buried soil horizon. Cook and Heizer (1965) concluded from their studies of native American sites that total soil nitrogen along with carbon, phosphorus and calcium were the most significant indicators of past human activity,

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[42] As the soil carbon increases with burgeoning microbe population the amount of free nitrogen decreases.
[43] As to the removal of nitrogen in crop plants and through consumption by livestock and people, it is assumed this is returned to the soil in the normal cycle of subsistence.
[44] An exception is work done on nitrogen isotopes in buried human bone fragments indicative of marine diets – Antoine *et al*, (1992).

more so than the heavy metals copper and zinc. The two Americans emphasised, however, that nitrogen was not in itself a reliable and persistent indicator, but elevated levels were associated with soils rich in organic forms of phosphorus and other organic residues. In other words the organic reservoir had survived. It was essentially the carbon : nitrogen : phosphorus ratios that provided Cook and Heizer with useful human-settlements correlations. During the excavation of a Neolithic burial mound at New Grange, County Meath, Gardiner and Walsh (1966) analysed buried soil profiles for organic carbon, total nitrogen, phosphorus and iron. Although some use was made of carbon: nitrogen ratios, phosphorus assessments were considered to be a more profitable line of investigation.

PHOSPHORUS: Unlike the non-metal elements sulphur, chlorine and nitrogen, soil phosphorus is relatively immobile and unquestionably accumulates over time on sites of human activity. This quality parallels that of heavy metals. Of all the elemental constituents of anthropogenic residues, phosphorus has the longest history of archaeological investigation. Scientific analyses of soil phosphorus dates back to the 1920s and the lessons learned from the slow evolution of this technique are relevant to the general development of archaeological soil chemical analysis. It is because the work on soil phosphorus has both demonstrated the pit-falls and set the accepted ground rules for archaeological geo-chemical surveying that, rather than present it here, it will be expanded upon in detail in Section 2.6[45].

C. ELECTRO-MOTIVE ELEMENTS

The Earth's crust is largely (92.8%) made up of the elements oxygen, silicon, aluminium, hydrogen and iron. Almost all of the remainder is potassium, sodium, calcium and magnesium in roughly equal proportions. This distribution, with the inclusion of organic carbon, is largely reflected in the composition of soils (see Table 2.32).

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[45] Section 2.6 considers sources of phosphorus, its natural cycle in the soil and the effects of human intervention, in particular that of modern agriculture. A critical review of soil phosphorus analysis as an archaeological technique from its inception in the 1920s to the present time is provided.

Table 2.32 Elemental composition of soil (after Bowen, 1979)

element	mg per kg soil	
	median	range
oxygen	490,000	*variable*
silicon	330,000	250,000 - 410,000
aluminium	71,000	10,000 – 300,000
iron	40,000	2,000 – 550,000
carbon (org)	20,000	7,000 – 500,000
calcium	15,000	700 – 500,000
potassium	14,000	80 – 37,000
sodium	5,000	150 – 25,000
titanium	5,000	150 – 25,000
magnesium	5,000	400 – 9,000
nitrogen	2,000	200 – 5,000
manganese	1,000	20 – 10,000
phosphorus	800	35 – 5,300
sulphur	700	30 – 1,600

Potassium, sodium, calcium, magnesium (and aluminium) are all metals high in the electromotive series. Their greater ability to lose electrons generally means that their salts are more water soluble and, what is of importance in the context of this discussion, more prone to leaching. The proportion of these metals existing in a water soluble form is, therefore, important.

In simple terms, potassium, sodium, calcium and magnesium occur in the soil in several forms which have been defined by soil scientists in terms of their availability as plant nutrients. Often the bulk of these metals is bound up in soil minerals derived from the parent rock. Such minerals typically weather on a geological time scale and the electro-motive elements they contain are, as such, classed as *unavailable*[46]. These primary mineral repositories are not chemically or physically affected by additions to the soil. The rest, the so-called *available* fraction, is, for the most part, tightly bound within the crystal lattices of clay particles. Only a tiny proportion exists in solution or loosely adhering to the outer surfaces of the clay . These labile elements are available as nutrients to plants in the immediate to short term. There is an equilibrium between the non-labile lattice bound elements and the labile plant available forms: when there is a dearth of the latter there is a slow release of the former. This equilibrium between different *species* of particular elements is affected by various factors, perhaps most important of which is the availability of competing free ions of hydrogen in the soil, in

[46] Specifically, that is, "unavailable" as plant nutrients, but also having a relatively neutral affect on the process of accumulating residues.

other words soil acidity. It would appear, therefore, that, as potential long term indicators of past human activity, the electro-motive elements derived from human sources are disadvantaged by their greater soil mobility. That is, over a period of time, they are more likely to be leached from the soil.

There are further factors that should mitigate against potassium, sodium, calcium and magnesium as anthropogenic markers. The first is that they are less efficient at forming ligands with soil persistent organic molecules. This will be discussed more fully below. Secondly, the soil cycles of these particular elements are liable to saturation and exotic additions from human sources can very often make little impression. The amount of sodium and magnesium, for example, deposited on soil by rain water (and enhanced by marine spray drift up to tens of kilometres inland) is potentially large enough to mask any anthropogenic source of these elements. The sodium : calcium ratio is, for example, 22:1 in oceanic locations like the Orkney Islands, but nearer 1:1 in continental Europe (Martin, 2000, pers.com.). Investigating archaeological sites near the sea for Na or Mg could be a problem. Potassium is a different story. It plays a dominant role in biomass circulation and most of the potassium that reaches the soil is washed from the surfaces of leaves. This element is far more abundant than sodium or magnesium in the soil and has the potential to mask any additions to the soil derived from human activity. Calcium is even more abundant. In arable soils calcium is the most common cation in soil drainage. It is worth noting that cation displacement (the release of these more electromotive metals into leachable soil solution) is accelerated in cultivated soils where the associated processes of nitrification produce an excess of (displacing) hydrogen ions and of (attracting) nitrate anions.

The amount of aluminium in the soil easily matches that of sodium, magnesium, potassium and calcium combined. It is the least electromotive of the suite of metals under consideration, and behaves somewhat differently in the soil. Aluminium ions (like iron) are more easily hydrolysed, particularly in acid (low pH) soils. These hydroxy-aluminium ions polymerise and precipitate in and on clay particles. The hydrolysis of aluminium ions can also result from adsorption of this element into organic matter. Despite its different behaviour, it is chiefly the natural abundance of this element that would mitigate against its choice as an anthropogenic indicator.

Notwithstanding the theoretical drawbacks, archaeological soil analysis for anthropogenic electromotive metals such potassium, sodium, calcium, magnesium and

aluminium has been adopted with apparent success, particularly for potassium. Such work has been undertaken mostly in the USA where sites in less agriculturally disturbed soils are (or were) more common (see Table 2.33).

Table 2.33 Archaeological soil analysis for anthropogenic electromotive metals.

author	date	electro-motive metal				
		potassium	calcium	sodium	magnesium	aluminium
Lutz	1951	✓	✓			
Sokoloff *et al*	1952					✓
Mattingly *et al*	1962	✓	✓			
Cook *et al*	1965		✓			
Griffith *et al*	1980				✓	
Griffith *et al*	1981	✓	✓		✓	
Butzer	1981	✓				
Ottaway *et al*	1982		✓			
Konrad *et al*	1983		✓		✓	
Woods	1984	✓	✓		✓	
Moore *et al*	1988	✓	✓		✓	
Ottaway *et al*	1988		✓		✓	
Linderholm *et al*	1994		✓			
Entwhistle	1994	✓	✓		✓	
Schuldenrein	1995	✓	✓	✓	✓	
Middleton *et al*	1996	✓	✓	✓	✓	✓
Evershed *et al*	1997	✓	✓	✓	✓	
Rimmington	1998	✓	✓	✓	✓	✓

Authors of work in North America are highlighted in **bold type**.

Many of the earlier investigations borrowed from crop nutrition and measured "exchangeable" cations, but this gave way to total soil content estimates. The 1990s saw the adoption of multiple element analytical techniques (in **red** in the Table 2.33) such as inductively coupled plasma emission spectrometry (ICP-ES). It then became relatively easy to include the electromotive elements in the test array as a matter of course – see Section 2.2.

It can be seen that, of those elements that form the bulk of anthropogenic residues, many do not survive in the soil over any great length of time. The exceptions are notably phosphorus and certain organic molecules. It is also apparent that, in some circumstances, electromotive metals and even nitrates might have a measurable

persistence. This now leaves us to consider a small remaining percentage of anthropogenic residues that include heavy metals.

D. HEAVY METALS

Finally, in this review of residues that derive form anthropogenic deposits which has, so far, included organic carbon, sulphur, chlorine, nitrogen, phosphorus and the more electromotive metals we come to the group of elements often referred to as heavy metals. In the introduction to this dissertation it was made clear that there was an intention to make heavy metals the focus of the present study. Under the direction of Dr Mike Martin, a specialised unit in the Biological Sciences Department of the University of Bristol has, over many years, established a reputation for research into the causes and consequences of heavy metal pollution in the modern world. Heavy metals are very soil persistent (Coughtry *et al*, 1976; Martin *et al*, 1982) and had already been used as site indicators by archaeologists (Sokoloff *et al*, 1952: Woods, 1984; Ottaway *et al*, 1988; Davies *et al* 1988). A series of heavy metal studies, undertaken on behalf of the Shapwick Project (see Introduction) and under the supervision of Dr Martin, proved very successful (Aston et al, 1998 a, b & c). This initial work, together with the pollution expertise available within the University and the access to laboratory facilities set up specifically for this type of research, an emphasis on the evaluation of heavy metals in soil was almost inevitable. However, a balance has been stuck by giving equal emphasis to certain non-metallic elements (carbon and phosphorus) and to other soil properties such as magnetic susceptibility and pH. The residual accumulation in the soil of the more electromotive metals was not studied.

The term '**heavy metal**' has been variously defined and is not really an entirely satisfactory description of the group of elements under consideration. One common definition is of metals with densities of 5 g cm^{-3} or more, but in terms of chemical properties this includes a diverse selection of some sixty nine elements. An attempt to reduce this group to those most commonly occurring in anthropogenic residues has been made on the basis of their chemical ability to form persistent metal/ion ligand

complexes[47] (Martin & Coughtrey, 1982, pp 1-2). Among these ligand forming elements are the following metals and metalloids (see Table 2.34);

Table 2.34 Ligand forming metals and metalloids

Antimony	Indium	Rhodium
Arsenic	Iridium	Silver
Bismuth	Iron[48]	Thallium
Cadmium	**Lead**	Tin
Cobalt	**Manganese**	Titanium
Copper	Mercury	Vanadium
Chromium	**Nickel**	**Zinc**
Gallium	Palladium	
Gold	Platinum	

Those elements in italic are metalloids. The metals in **bold type** are those under study in this thesis and the reasons for their selection and the omission of others are discussed later.

The following table (Table 2.35) gives some indication of their occurrence in the lithosphere, the soil and in plants.

Table 2.35 Typical concentrations of heavy metals - after Jones *et al* (1981) & Wild (1993).

Metal	Earth's crust	Soils	Soils*	Plants
	$\mu g\ g^{-1}$	$\mu g\ g^{-1}$	$kg\ ha^{-1}$	$\mu g\ g^{-1}$
cadmium	0.1	0.01 - 2.4	0.02 - 4.8	0.2 – 0.8
chromium	100	5 - 1500	10 - 3000	0.2 – 1.0
cobalt	40	1 - 40	2 - 80	0.05 – 0.5
copper	50	2 - 250	4 - 500	4 - 15
iron	50,000	7,000 – 550,000	14,000 – 1,100,000	140
lead	14	2 - 300	4 - 600	0.1 - 10
manganese	1000	100 - 4000	200 - 8000	15 - 100
mercury	0.05	0.01 - 0.3	0.02 - 0.6	0.015
molybdenum	2.3	0.2 – 2.5	0.4 - 5	1 - 10
nickel	80	2 - 1000	4 - 2000	1
tin	40	2 - 200	4 - 400	0.3
zinc	75	10 - 300	20 - 600	8 - 100

* amount of metal per hectare calculated for a soil depth of 15 cm and a bulk density of 1.3 (approximate mass 2000 tonnes).

Note: the ranges quoted include soils that have been industrially/mineralogically contaminated, i.e. the higher values are beyond those to be expected in natural soils.

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[47] Although clay particles can and do act as short to medium term repositories of metal ions there is a limit to the size of the soil clay fraction. The organic ligands associated with heavy metals are probably a more important factor.

[48] Iron has a similar abundance (2%) in the Earth's crust to the electromotive metals and is by far and away the dominant heavy metal in soils. It is not being considered as a candidate marker because of its abundance and also because (like aluminium) its behaviour in the soil is complex.

In many ways the soil chemistry of the heavy metals selected for study is very similar. They are all, to a small degree, present as solutes in the soil water (often as bicarbonates or sulphites - Leeper, 1978, 11) and thereby open to leaching (although considerably less so than the electromotive metals discussed above). Nevertheless, released heavy metal ions are quickly re-adsorbed on to new adsorption sites. These metals can, just like all cations, integrate themselves into the crystal lattices of clay particles. In the normal range of soil pH (5 to 8) heavy metal ions compete with and displace those of the more electromotive metals. They are all (like aluminium and iron) prone to hydrolysis i.e. re-acting with water to form hydroxides and hydroxy complexes. These hydroxy compounds can merge with other molecules forming very insoluble residues. Further, and importantly, the bivalent (occasionally trivalent) ions of heavy metals can bond very effectively with organic matter by a process of ionic exchange called *chelation*[49].

When considering the behaviour of heavy metals in the soil the importance of pH has to be emphasised. For example, fresh organic deposits tend to acidify the soil[50] and enable the initial release of heavy metals. As the organic matter dissipates the pH increases supporting the stability of the bonding of heavy metals with organic ligands (Jones *et al*, 1981, 604, Leeper, 1978, 21). Copper forms the most stable complex over a wide range of pH and, in the group under consideration, cadmium is the least stable.

$$\mathbf{Cu^{++} > Pb^{++} > Ni^{++} > Co^{++} > Mn^{++} > Zn^{++} > Cd^{++}}$$

All the heavy metals studied in this thesis are soil persistent. Most are essential as trace elements for plants or animals (the exceptions being lead and cadmium) and all, if overabundant in the soil, are toxic[51]. All the metals listed in the table above normally occur in soils as cations. If the conditions are right and for short periods, chromium molybdenum can occur as anions[52].

A study of anthropogenic soils in Native American middens (Sokoloff & Carter, 1952) was the first to confirm that heavy metals (copper and zinc) were persistent markers of

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[49] *Chelation* is the gripping of a metal ion by two or more linked atoms to form a stable ring ... from the Greek *chele*, meaning claw.

[50] This, of course, depends on the soil pH at the start. Also some plant materials, viz. elm and hazel, are soil improvers and can increase soil pH, whilst beech and pine lower pH (Martin, pers. com.)

[51] Cadmium, cobalt, copper, chromium, lead, manganese, nickel and zinc are all generated by modern industrial processes or in automobile exhaust and are potential pollutants. The impact of modern pollution on archaeological geo-chemical assessments is discussed in the next section.

[52] Molybdenum can form the *molybdate* anion and chromium the *chromate* anion.

human activity. But it was not for another thirty years that further studies were undertaken. Woods (1984) got poor results attempting to associate iron, copper and zinc with the occupation of a two hundred year old fort in Illinois. Ottaway and Mathews (1988) published soil analysis data from an excavated occupation mound (*Tell Gomolava* - Neolithic to medieval) in Yugoslavia which gave encouraging results for copper, zinc, manganese and nickel. Jenkins (1988) found enhanced levels of chromium, cobalt, lead, nickel and especially tin associated with charcoal debris from various archaeological sites. Davies *et al* (1988) examined soils taken from Bronze Age farmsteads, villages and cities in Boeotia, Greece and found clear correlations of copper, lead and zinc with ancient human activity. With the introduction of ICP multi element analysis in the mid 1990s a wide range of heavy metals were introduced into the scanning array. Amongst the relatively small number of studies published in the last decade was an evaluation of 18th century manuring of arable land and of associated settlements on Skye (Entwistle, 1994 &1998) which recorded soil enrichment by caesium, rubidium, thorium, and strontium although other heavy metals (including cobalt, copper, lead and nickel) demonstrated no enrichment at all. These studies are summarised in Table 2.36

Table 2.36 Archaeological soil analysis for anthropogenic heavy metals.

author	date	cadmium	cobalt	copper	chromium	iron	lead	manganese	nickel	zinc	other
Sokoloff	1952		✓	✓	✓	✓		✓	✓	✓	
Woods	1984			✓		✓				✓	
Ottaway	1988			✓	✓		✓	✓	✓	✓	✓
Jenkins	1988		✓		✓		✓		✓		✓
Davies	1988			✓			✓	✓*	✓*	✓*	
Linderholm	1994		✓	✓	✓	✓		✓			✓
Entwhistle	1994		✓	✓	✓	✓	✓	✓	✓	✓	✓
Middleton	1996					✓		✓		✓	✓
Evershed	1997		✓	✓	✓	✓	✓	✓	✓	✓	✓
Rimmington	1998	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

* Data published in a subsequent paper.

Authors in italic indicate their use of multi-element analysis using ICP

2.4.2 RESIDUES DERIVED FROM INORGANIC DEBRIS

Finally, it is necessary, for completeness sake, to mention the fate of inorganic residues from anthropogenic processes. As stated in the introduction to this Section these residues are by-and-large associated with high temperature processes and survive, or derive from, anthropogenic deposits such as elemental carbon (e.g. charcoal, soot etc), metallic oxides and salts, particles of metals and heat-altered clay debris (baked clay, daub, fragments of pottery, tile and brick). An exception to the high temperature qualification is, of course, flint debris from pre-historic tool and weapon knapping.

Elemental carbon is subject to gradual oxidation if exposed to the atmosphere and charcoal and soot (just like the dry exposed surfaces of peat land) will eventually be lost as carbon dioxide. If buried, especially in wet anaerobic conditions, charcoal flakes and other carbonised fire debris can be preserved for thousands of years.

Most of the metal debris associated with small settlements is likely to be iron associated with smithing. Again, unless anaerobic conditions prevail, small iron fragments and particles will oxidise rapidly in the soil. These and other iron oxides are soon converted to salts and hydrolysed thereby engaging in the dynamic chemistry of the soil where indeed anthropogenic accumulations may be detectable.

Ceramic material, unless particulate or where the soil conditions are very acid, is fairly inert and most degradation will result from physical and climatic weathering. Survival of pottery sherds can provide a useful indicator of manuring practices against which the survival of elemental residues can be measured (Rimmington, 1998).

Summary

This Section has looked at the survival and relative persistence of human deposits and their residues over time. Most anthropogenic deposits are organic in origin and the vast bulk of these deposits (the hydrocarbons) are lost in the short term to the atmosphere. However, not all organic matter is short lived and residual "humic substances" including lipids survive for considerable periods of time. Among the non-metallic elements common in anthropogenic deposits, phosphorus has a demonstrable persistence (see Section 2.6) whereas sulphur and chlorine have a fairly rapid turnover. A similar turnover would be expected for nitrogen but there is some evidence that enhanced levels survive where there is no major depletion of soil organic matter. Similarly, it is difficult to dismiss the electromotive elements. Despite their relative solubility and their propensity to be lost over time by leaching, there is evidence that human enhancement of certain of these elements (notably potassium) remains measurable for hundreds of years[53]. However, among the anthropogenic elements, heavy metals appear to be among the most persistent of markers, being very long term if not permanent residents in the soil. This is why they have been chosen as indicators of human settlement and activity in this piece of research.

That residues from past human activity persist over time is one thing: being able to recognise them today is quite another. The next Section considers those factors by which anthropogenic residues might be disturbed, destroyed or obscured and how, despite these disruptive influences, they might still be measured.

[53] Leaching can deplete the surface layers but leave residues at lower levels of the soil profile. Relative compaction, permeability or composition of the different soil horizons could affect this.

SECTION 2.5. THE RECOGNITION OF ANCIENT ANTHROPOGENIC RESIDUES

Having described the surviving human residues that are most likely to be associated with past human settlement or activity it is now necessary to consider how these alterations to the soil can be *recognised*. For the reasons explained in Part 3, the following research concentrates on evidence from a limited array of heavy metals together with phosphorus and carbon. How these elements might be *evaluated* is discussed in the next Section (for phosphorus) and in Part 3.

Within traditional archaeological procedures, be it excavation, aerial photography, field walking etc, the recognition and evaluation of sites and finds are generally straight forward. It is seldom considered necessary to define the unaltered (in a relative sense) environment in which the current archaeological evidence sits. This is understandable as artificially altered environments are often quickly recognisable to the trained eye even if elucidation requires some recourse to technology, e.g. geo-physical surveying. The archaeology is itself seen as a manifest alteration to what went before, be it the superimposition of ditches or walls revealed by excavation, or the presence of vestigial anomalies in the landscape, such as discontinuities in field boundaries. Even when examining primeval disturbances, such as a prehistoric camp site, the evidence for the presence of humans is, when expressed in flint scatters or cut marks on bones, on the whole, unambiguous.

When archaeology is applied purely to the chemistry of the soil, for example in circumstances where little conventional evidence is obvious or none has survived, or where supplementary evidence is being sought, the changes attributable to human activity become clear only when they can be measured against (again in a relative sense) the unaltered environment.

2.5.1 THE NATURAL BACKGROUND

A. NORMAL CONCENTRATIONS IN THE SOIL

The concentration of elements within the soil will show some variation according to the nature and origin of the soil itself. Its mineral composition is derived from the parent material which might be, amongst other possibilities, acidic or basic igneous rocks, metal-enriched metamorphic rocks or sedimentary rocks formed from blown sand,

marine silt or thick calcareous deposits. Some soils are not related to the underlying geology, but are associated with superficial glacial, wind-blown (loess) or alluvial drift material. In turn the soils associated with such parent materials will also vary in elemental composition from one type to another[53]. The following table (Table 2.37) shows the range of values of certain soil elements found in England and Wales and these are compared with the range of values measured at one of the locations studied in this thesis.

Table 2.37 Normal levels of elements in soils.

Element	Normal range mg/kg *	Median value mg/kg *	Range for Shapwick* soils mg/kg	Median value Shapwick* soils mg/kg
Cadmium	0.08 - 10	<1	0.3 –2.9	0.66
Chromium	5 - 1000 **	100 **	10.3 – 32.4	19.0
Copper	1.8-195	17	28.4 – 55.6	42.0
Lead	5 - 1200	42	25.3 – 90.5	34.4
Manganese	100 -4000 **	800 **	258 - 1573	812
Nickel	4.4 - 228	26	25.4 – 52.0	40.3
Zinc	5 - 816	77	89.1 – 200.4	129.2

* the figures from farmland soils in England and Wales (Archer 1980).

** data for chromium and manganese (Berrow & Burridge 1980).

* data from Church Field, Shapwick in Somerset (see CD).

It can be seen that all of the elements fall within the normal range but, for the closely related soil types found at the studied site, the range is noticeably wide. In any comparative study of heavy metals in the soil it is important to consider what the normal concentrations of elements are for the soil types occurring in the investigation area, and to be aware of any changes in soil type that may be present. The Soil Survey of England & Wales has produced soil maps from which major variations in the soil type (referred to as the Soil Series) can be deduced.

If soil metal analysis is to be of use in archaeological investigations it will be by or from the recognition of a pattern of anomalous concentrations over and above any variation in the normal concentrations present. A useful technique in this situation could be the expression of concentrations normalised to the lowest concentration of that element found in soils at the specific site of investigation.

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[53] see Archer, 1980 for data on soils from a range of parent materials in England and Wales.

It is rare, at least in England and except possibly in ancient woodlands, to find soils that have not been modified by human activity. It is therefore difficult to perceive a critical control situation where measuring the natural (i.e. total absence of any interference by people) variation of field soils would be possible. The literature suggests that variation in elemental concentrations in field soils is large, especially for potassium, phosphorus, magnesium, iron and manganese, but much smaller for the less abundant elements such as zinc and copper (Beckett & Webster, 1971; Kahn & Nortcliff, 1982). However, the sites used by these authors were from agricultural land and their results are not applicable for use as control data.

B. PATTERNS IN THE DISTRIBUTION

Patterns in the distribution of metals in soil could arise from natural causes where for example waterlogging occurs; in this situation iron and manganese are susceptible to changes in *redox* state which causes their mobility to be increased under anaerobic (waterlogged) conditions. Thus any spatial patterns in the concentration of manganese could be related to patches of variable waterlogging caused by topographical effects even on a small scale.

The occurrence of patterns in the chemical composition of soils related to vegetation features is well known (Jackson & Caldwell, 1993). Zinke (1962) showed a radial pattern in nitrogen, carbon and soil pH related to the extent of tree canopies growing in sandy soils in USA. In an archaeological context most sites showing soil disturbance will be mostly larger than any pattern that could have been imposed by plants even as large as individual trees.

2.5.2 MODERN FARMING PRACTICES

A. LOSSES BY CROPPING

Plant roots penetrate soil often to remarkable depths and every plant growing on a soil will absorb, to a varying degree, a proportion of the metals in the soil, the exact proportion depending on soil composition, soil characteristics, plant rooting pattern and

individual plant species. It is feasible that large scale and continuous long-term cropping of a field would deplete the soil of substantial quantities of metals, so that, over time, continued removal of crops could significantly reduce or alter any anomaly caused by past human activities or general habitation (see Table 2.38). Calculations of the residence times of metals in soil in relation to cropping (see below) suggest that nickel, chromium and lead in particular will persist in the soil for thousands of years. Cadmium on the other hand may have a much shorter residence time. The actual uptake and accumulation of metals by crop plants from soil will depend on the bioavailability of the individual metals; this is closely related to mobility in soil and factors such as the acidity of the soil will play a dominant role in determining this (see above). The order of retention, expressed as the number of croppings needed to reduce concentrations in the soil by 99.9% is :-

Nickel>Chromium>Lead>Copper>Zinc>Cadmium

Table 2.38 Number of croppings needed to reduce soil metal concentration by 99.9%.

Element	Soil at start mg/kg	Plant at start mg/kg	Croppings needed
Cadmium	0.35	0.25	2095
Chromium	8	0.5	23944
Copper	30	9	4988
Lead	10	1	14968
Manganese	500	250	2993
Nickel	50	1	74832
Zinc	90	40	3368

Calculations based on average soil and plant concentrations (data from Bowen, 1979) of the number of croppings needed to reduce the concentration of the specified element to 0.1% of its starting concentration. Assumptions are that soil bulk density is 1.3 g/cm^3; that plant concentrations reduce proportionally as soil concentrations decrease; the annual crop removed is 1.2 kg/m^2; and no other factors reducing or adding to the soil metal concentrations were considered in the calculations.

B. POTENTIAL EFFECTS OF AGRICULTURAL FERTILISERS

The modern-day agricultural use of soil fertilisers can result in the addition of considerable quantities of certain metals that occur as impurities. The following table (Table 2.39) gives some examples of the concentration ranges of elements within fertilisers and soil additives. It should be noted that sewage sludge (see below),

inorganic phosphate and nitrogen fertilisers are of modern origin. In all cases the degree of contamination will depend on the quantities of additive applied.

Table 2.39 Concentrations of elements in commonly used fertilisers and soil additives

Element	Phosphate fertilisers	Limestones	Nitrogen fertilisers	Manure	Sewage sludge
Cadmium	0.1 -170	0.04 - 0.1	0.05 - 8.5	16 -41	2 - 1500
Chromium	66 - 245	10 - 15	3.2 - 19	5.2 - 55	20 - 40600
Copper	1 - 700	2 - 125	<1 - 15	2 - 60	50 - 3300
Lead	7 - 225	20 - 1250	2 - 27	6.6 - 15	50 - 3000
Manganese	40 - 2000	40 - 1200		30 - 550	60 - 3900
Nickel	7 - 38	10 - 20	7 - 34	7.8 - 30	16 - 5300
Zinc	50 - 1450	10 - 450	1 - 42	15 - 250	700 - 49000

Data are in mg/kg dry weight, after Kebata-Pendias & Pendias (1985).

The implications to phosphorus evaluations by the application of super-phosphate fertilisers is discussed in the next Section.

C. POTENTIAL DISTURBANCES BY RECENT APPLICATION OF SEWAGE SLUDGE AND SLURRIES

Because of the nature of the sewerage system in Britain at the present time, domestic sewage becomes mixed with industrial waste-waters and street drainage water. As a result considerable contamination of the resulting treated sewage sludge with metals occurs; the composition of the sewage sludge is highly variable and often reflects local industries. Thus towns with photographic processing works have traditionally produced sewage sludge enriched in silver, whilst street drainage-water is often contaminated with chromium from the chromate paints used in yellow-line road-markings and lead deposited from petrol-vehicle exhaust. (See Table 2.39 for the extent and range of metal contamination of sewage sludge.)

With potentially such highly contaminated material the agricultural use of sewage sludges could mask any prior patterns in the surface soils that might have had archaeological interest. However, like most fertiliser applications, they are evenly spread and the concentrated patches of ancient enrichment persists (see discussion on the application of modern phosphorus fertilisers in Section 2.6).

The use of modern agricultural slurries could also be potential sources of additional metal to soils. In a similar way to sewage sludge of human origin, farmyard manure

and other slurries could cause changes to the distribution patterns of metals in soil. Of particular note should be the use of pig-slurries; copper is used as a supplement to enhance growth of pigs, this results in pig slurries containing high concentrations of copper (Unwin, 1980).

D. THE EFFECT OF PLOUGHING

Agricultural cultivation practices such as ploughing cause mixing of the surface layer of the soil. This has three main effects, possibly blurring the edges of any pattern that may pre-exist soil cultivation, the mixing of soil within the plough-layer, and the potential lateral movement of the soil in the plough layer. The effects of soil cultivation (particularly the implications to sampling) are discussed more fully in Part 3.

2.5.3 POLLUTION

A. RECENT INDUSTRIAL ACTIVITIES

If the chemical analysis of soil is to be useful as an archaeological tool, the area under investigation should also be free from recent pollution episodes. The impact of post industrial revolution heavy metal smelters and foundries, such as the lead-zinc smelter at Avonmouth near Bristol, for example, has imprinted a pattern of concentrations of lead, zinc, cadmium and copper on soils in the vicinity that will be discernible for many centuries to come (Little & Martin, 1972; Martin & Bullock, 1994; Martin & Coughtrey, 1982). Elsewhere metal mining activities have contaminated adjacent soils: areas such as the Mendip Hills contain several sites where lead, and zinc mining and processing have occurred. These activities date from pre-Roman to the 19th Century with consequences on the metal contents of local soils (Martin & Fawcett, 1997). In places, for example at Shipham in Somerset, zinc mining has left soils highly contaminated with both zinc and cadmium, whilst not far away at Priddy and Charterhouse contamination is primarily by lead with some zinc.

B. PROXIMITY TO MAJOR ROADS

Over the period 1940s to 1990s motor vehicles used petrol with considerable additions of lead as an anti-knock agent. The introduction of unleaded petrol in 1985, and its rapid increase to dominate the petrol market in the mid 1990s, has significantly reduced the amount of lead emitted to the atmosphere from petrol driven motor vehicles. The

dispersal of lead in exhaust gases causes fallout of lead to vegetation and soils within a zone of about 50 metres of the road margin (Chamberlain *et al*, 1979). Additional lead aerosols remain in the atmosphere for much longer and contribute to long distance dispersion. Because lead has a very long residence time in soils, sites within 50 metres of a busy road can be expected to show enhanced lead concentrations. In rural areas, roads with little traffic and with substantial roadside hedges or banks can be expected to show only minor disturbances of any other patterns in soil lead. Whilst other elements have been shown to be related to motor traffic, resulting from oil, engine wear and tyre wear, these are minor compared to lead and are likely to be confined to a much narrower zone adjacent to the road itself.

Summary

There are clearly sites where the technique of using heavy metal analysis of soils to identify small settlements or localised past activities of archaeological interest would not be justified, such as where there are natural outcrops of metal bearing rocks and occurrence of soil derived from those rocks. The considerations described above also indicate that there are likely to be a considerable number of precautions and considerations that should be taken into account in the interpretation of any data resulting from this method. Nevertheless, heavy metals have been chosen because they are persistent and cumulative in the soil and probably more so than other metals. Being trace elements or rare earths any exotic additions to their natural levels can prove a prominent marker. But they are also toxic and, if present in the soil in excess, are considered as pollutants. The techniques and methodologies used in this thesis, as has been stated in Part 1, have been based on a pollution science approach and it can not be denied this will also have influenced, together with the laboratory facilities that were available, the choice of elements investigated.

Phosphorus, like heavy metals, is also persistent and cumulative in the soil and the final section in Part 2 provides a detailed review of soil phosphorus analysis as an archaeological technique.

2.6 A REVIEW OF SOIL PHOSPHORUS ANALYSIS AS AN ARCHAEOLOGICAL TECHNIQUE

The chemical analysis of soils to determine the location, geographical extent or nature of past human activity has a long provenance. The association of soil phosphorus enrichment with ancient settlements is even longer. In Egypt, in 1911, F. Hughes noted the association of elevated soil phosphorus levels with ancient habitation sites (Russell, 1957, 181). In the 1920s, a Scandinavian researcher, Olaf Arrhenius, whilst surveying some half a million hectares of southern Sweden for sugar beet production, was able to confirm a close coincidence of abnormally high measurements of soil phosphorus with areas of past human activity. From the publication of Arrhenius's work the chemical analysis of soil became an established archaeological technique. Over the last 70 or 80 years this technique has been revised and refined. It has also been misused and misunderstood and, as a consequence, it has been, at times, criticised as unreliable or too cumbersome. More recently it has at last become accepted as a routine procedure in many archaeological investigations.

The lessons learned from the slow evolution of soil phosphorus evaluation as an archaeological technique are relevant to the developing techniques of wider soil chemical analysis. It is because the work on soil phosphorus has set the accepted ground rules for archaeological geo-chemical surveying that it is expanded upon here.

However, it should be noted that the evaluation of soil phosphorus in an archaeological investigation is comparative and, at times, arbitrary. It is seldom an absolute measurement of what is there and rarely, if ever, is it possible to determine what part of this phosphorus is wholly derived from human activity. Often the result obtained will be determined by the analytical procedure adopted, and for any result to be significant to the investigator it must differ from what might be defined as the normal "background" level. To define what is a normal "background" level requires an understanding of the origin of soil phosphorus and of its dynamic soil chemistry.

The following subsections in this Section will examine the sources of soil phosphorus, both natural and anthropogenic; the fate of phosphorus once it enters the soil; why it persists in the soil for considerable periods of time, how archaeologists have measured it, the problems inherent in interpretation of these measurements and finally the prospects for future work with specific reference to the inclusion of other soil elements.

2.6.1 THE SOURCES OF PHOSPHORUS IN THE SOIL

Phosphorus is ubiquitous on this planet ranking as tenth among the common elements. It has been estimated that almost all (98%) of this phosphorus is contained as silicate minerals in the lower mantle and core (Sun & Nesbitt, 1977) and as such plays no part in the phosphorus cycle. In the oxidative conditions of the upper mantle and crust the element is present as phosphate, i.e. P_2O_5. The concentration of this cycleable phosphate as constituent components of the planet's surface rocks and sediments was summarised by Brinck (1978) as follows (see Table 2.40).

Table 2.40 Percentage of total planetary phosphorus (after Brinck, 1978)

lower mantle and core	98%
upper mantle	1.53%
crust	0.1%
igneous rocks	0.1%
marine sediments	0.12%
continental sediments	0.07%
soils	0.08%

Phosphorus within the lithosphere (and derived from the upper mantle) occurs in small quantities in most igneous and metamorphic rocks. Although over two hundred forms of mineral phosphorus have been described (Koritnig,1978), **apatite** is far and away the most common. Apatite, a calcium phosphate complex of low solubility, subsequently becomes a small component of derivative alluvium and eventually sedimentary rocks. Other insoluble phosphate minerals (including base-metal phosphates) associated with intrusive granitic pegmatites also find their way into sediments by the same process of erosion. A particular example is the lead phosphate mineral, **plumbogummite**. Another quantitative evaluation (Richey,1983) concluded that most of the phosphorus in the biosphere lies as sediments in the sea (see Table 2.41).

Table 2.41 Phosphorus in the bio-sphere (after Richey, 1983)

location	*$P \times 10^{12}$ kg*
marine sediments	840,000
marine solution	80.0
marine biota	0.05 - 0.12
terrestrial rocks	19.0
soils	96-160
terrestrial biota	2.6

Marine phosphates find their origin not only from continental outwashings but also from sub-marine volcanism. An appreciable amount (although a small percentage of the total i.e. 0.01%) of this marine phosphorus is in solution but can in certain conditions be precipitated to form phosphate rich sediments. The process is complex and involves the upwellings of cold mineral-rich deep-sea water into shallower waters; the activities of marine biota and gradual the creation of organic-rich sea-bed deposits. Subsequent reworking and chemical changes to these deposits lead to the direct precipitation of apatite. These phosphatised sediments form the phosphate-rich rocks (phosphorites) which are today commercially exploited throughout the world.

On dry land, however, most phosphorus is found in living organisms or in the soil. How phosphate enters the soil and its subsequent fate is described in the next section.

2.6.2 THE CYCLE OF PHOSPHORUS IN THE SOIL

As described above, there appears to be a simple ***geologic cycle*** of phosphorus whereby the element transfers from the upper mantle to the surface (continental or sub-marine) through intrusive or extrusive igneous activity during which process the mineralogy can become more complex. As a result of subsequent erosion these phosphates, largely apatite, eventually accumulate as marine deposits where, through plate tectonic activity, they are either uplifted by continental collision, or are subducted once again into the upper mantle. The creation of soil is a small part of this cycle. The phosphorus content of soils being primarily derived from geologic parent material and exists as phosphate (see Box 2.1).

The amount of phosphorus in a soil will vary with location depending on the source and nature of the parent material. It will be determined also by the amount of organic matter and organic activity the soil contains or supports, and the consequent physical structure and chemistry of the soil; all of which will be strongly influenced by climate. It is no surprise therefore that the amount of phosphorus in a soil can range from 500 to 2500 kg ha^{-1} (White, 1998, 205) of which between 15 -70% can occur in a biologically-unavailable inorganic form. The rest (30 - 85%) is organic phosphorus within living, dead or residual organic matter.

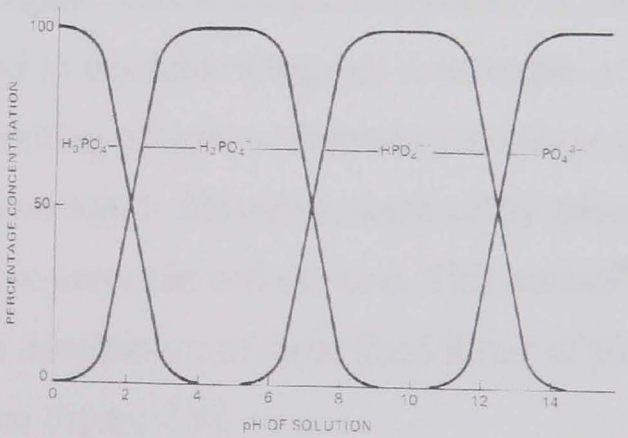
Soil phosphate or Soil phosphorus

Phosphorus is found in soil as its oxidised form in concentrations ranging from 100 to 1000 ppm.

"phosphate ion" $(PO_4)^{---}$

The 'phosphate ion" as such exists in extremely alkaline solutions which are not usually encountered in nature. Indeed, very little phosphorus (i.e. 0.05ppm) exists in the normal range of soil solutions. The tiny amount found in solution occurs usually as one of two orthophosphate ions, which one also depending on the pH.

orthophosphate ions $H_2PO_4^-$ and HPO_4^{--}



Brady 1974

Consequently, reference is commonly made to soil phosphates. However, since a large proportion of this element can exist in the soil in organic forms which are not phosphates the more appropriate term is **soil phosphorus**.

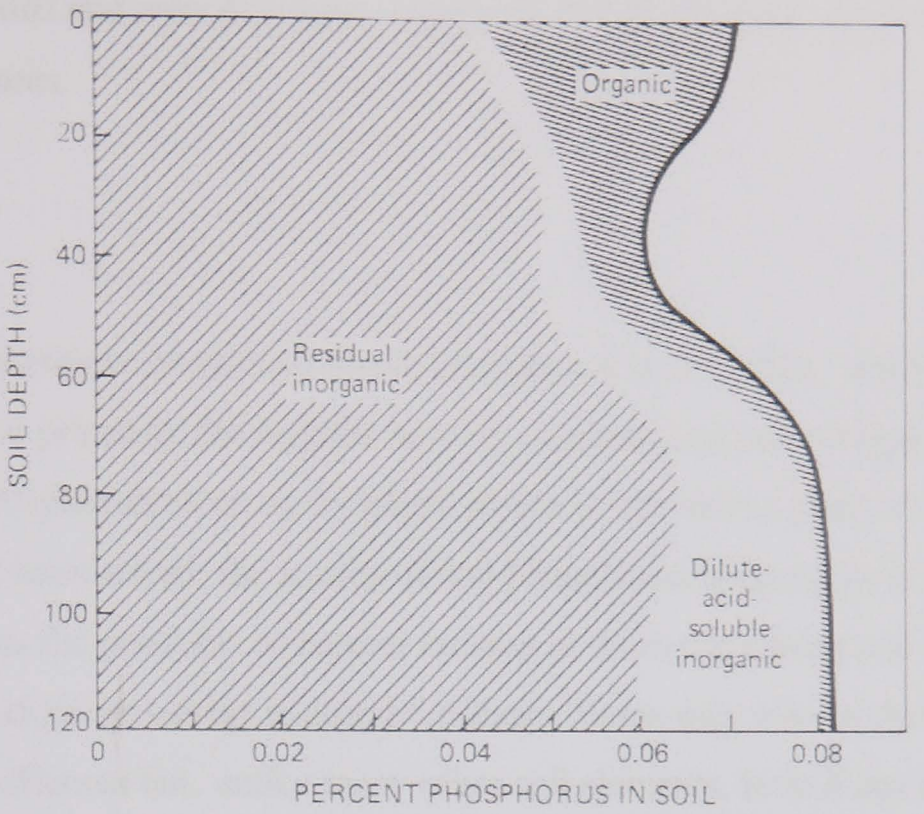
Box 2.1

Edaphic life forms are highly competitive; bacteria in particular having a greater requirement for phosphorus. In some soil conditions (e.g. in soils with a high C : P ratio) and because bacterial phosphorus residues are mainly insoluble (Ca, Fe, and Al inositol hexa-phosphate) plant growth can be limited by the shortage of available phosphorus. Generally, however, the role of micro-organisms is crucial in releasing (*mineralising*) otherwise bound organic phosphorus and making it available to higher plants. Some micro-organisms *(Aspergillus, Arthrobacter, Pseudomonas,* and *Achromobacter*) return inorganic phosphorus to the soil solution. Higher plants have in many cases evolved symbiotic associations with plant micro-organisms (e.g. a plant root/soil fungus association called *mycorrhiza*) to exploit soil phosphorus and other minerals more efficiently. These relationships can be disturbed, if not destroyed, by the injudicial application of artificial fertiliser and the plants suffer consequently.

Phosphorus that is released by the mineralisation of organic phosphates is in the form of orthophosphate ions, i.e. $H_2PO_4^{1-}$ and HPO_4^{2-}, which, if not taken up by plants or other organisms, is rapidly *adsorbed* onto soil particles and will over a relatively short time become unavailable once again. This is the process known as *phosphate fixation* where phosphorus is either bound to insoluble inorganic compounds or organic matter, or becomes *occluded* by a coating of iron or aluminium oxide (*sesquioxides*). This fixed phosphorus is classed as *non-labile*. However, some of the adsorbed phosphorus can be *desorbed* fairly easily and re-enter the soil solution. This accessible reservoir is known as *labile phosphorus*. The distribution of these fixed forms of phosphorus will vary through the soil profile (see Figure 2.6).

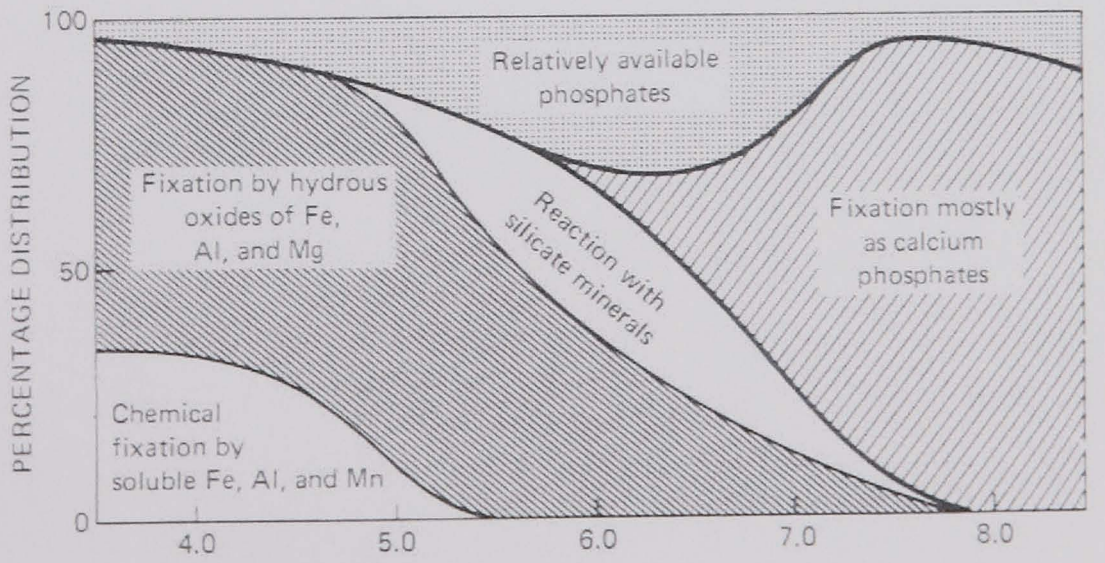
The amount of (plant) available phosphorus (i.e. solution phosphorus & labile phosphorus) is affected by the pH of the soil as well as by the quantity of clay particles, sesquioxides and exchangeable cations (e.g. aluminium and calcium) the soil contains. The interaction of these factors is complex (see Figure 2.7). In well fertilised acid soils the amount of available phosphorus increases with pH, whereas in well fertilised alkaline and calcareous soils it increases as pH falls. The optimum availability for both soils is between pH 6 and 7. However, in poorly fertilised acid soils, for example, because of the sorbent properties and polymerisation of exchangeable aluminium ions in these conditions, available phosphorus is at a minimum at the pH range quoted above and does not increase until the hydrogen ion concentration exceeds pH 7.

Figure 2.6. Distribution of phosphorus through a vertical soil profile (Brady 1974)



The figure illustrates the profile of a typical prairie soil (Iowa, USA). The relative proportions of the phosphorus fractions and the change in total phosphorus through the profile can, however, vary considerably with soil type and land use.

Figure 2.7 Fixation of phosphorus at different pH (Brady 1974)



Again the above figure (Figure 2.7) is illustrative of hypothetically average conditions and could vary markedly with different soils.

Phosphorus is not easily lost from the soil by leaching and any such losses are very small, e.g. less than 1 kg per hectare per year (White, 1998, 211). The only exceptions are very sandy soils and soils that have accumulated high amounts of artificial fertilisers and animal manures.

Setting aside the greater *geological cycle*, phosphorus is, therefore, whilst a component of the soil, cycled primarily through the activity of plants and micro-organisms. In nature all the phosphorus taken up by plants re-enters the soil as plant or animal residues. As has been stated, the source of soil phosphorus is primarily its parent material, either as the products of natural erosion or from the mining and refining of phosphorites (and guano) as agricultural fertilisers. Some may also be derived indirectly from industrial effluents but, unlike many other soil elements, little if any arrives as atmospheric fall out. Minimal amounts of phosphorus are leached from the soil to reach the sea in solution, and most will only arrive as eroded sediments. Indeed there are but two ways in which significant amounts of phosphorus leave the pedosphere, i.e. either by the physical erosion of soil into rivers and ultimately the sea, or by the deliberate removal of crop plants by human beings. Thus this smaller *biological cycle* is essentially stable in the human time scale and can only be distorted by abnormal activities. These imbalances are most often attributable to human intervention.

2.6.3 HUMAN INTERVENTION IN THE CYCLE OF SOIL PHOSPHORUS

A. THE PHYSICAL DISPERSAL OF PHOSPHORUS

The role of human beings in the biological cycle of soil phosphorus is essentially the same as for all animals, that is to consume soil derived phosphorus (in the form of plants or herbivorous animals) and then to excrete what is surplus to need. However, there are certain activities peculiar to human beings that can cause sort term (in a geologic sense) disturbances within the cycle. These are intensive and localised activities associated with settlement and farming, and extensive effects such as land clearance or industrial exploitation resulting from larger population pressures. Some illustrations of human manipulation of the phosphorus cycle are given below.

***Excretion**:* Most plants will grow, die and decompose *in situ*. Most animals will excrete at or near the place of feeding. As most animals will have to relocate for their next meal so the dispersal of phosphorus is equalised. But if animals have a habitual feeding location or are penned and fed, if their dung is allowed to accumulate, or is removed and stock piled, or is selectively distributed, then the dispersal of phosphorus will be unequal. If animals have a regular den, burrow or roost or if people chose to feed and excrete in a certain locality (either seasonally or permanently) phosphorus will accumulate in the soil disproportionately to the natural back ground levels.

***Fire**:* Where natural disasters occur such as forest or savannah fires, sufficient natural vegetation and soil organisms will survive to facilitate eventual regeneration. Indeed many eco-systems have adapted to such occurrences. Usually these chance fires are separated in time and fairly wide ranging so that the effects on soil phosphorus enhancement are uniform over a large area. Where people have regularly burned fuel for warmth, cooking or for industrial purposes, soil phosphorus elevation is localised. Also where humans have thoroughly cleared or burned large areas of vegetation for agricultural purposes and not allowed natural regeneration (as would be the case with nomadic cut and burn farming) the natural biological cycle of phosphorus may have been destroyed and farming become entirely dependent on artificial supplements. This too will create anomalies in the distribution and concentration of soil phosphate.

***Erosion**:* Rivers, oceans and wind also disperse phosphorus. Clearances of large areas of vegetation for agriculture or mining can result in desiccated soils being blown away by the wind, such as the notorious dust bowls of the mid-western states of the USA.

B. PHOSPHORUS DISPERSAL AND SPECIFIC HUMAN ACTIVITIES

The enhancement of natural soil phosphorus levels (and indeed other anthropogenic soil elements such as lead, zinc, copper etc.) can be attributed to several, often interlinking, human activities; disposal, accidental loss, storage and stock piling, deliberate dispersal, industry, building and fire (See Section 2.1).

C. MODERN AGRICULTURE

Any review of the effect of human activity on the phosphorus content of soil cannot avoid the impact of modern agriculture. All anthropogenic sources of soil phosphorus were, until the advent of artificial fertilisers, exclusively organic. All, with the exception of crop removal, enhanced the natural background levels of soil phosphorus thereby providing a positive indication of human activity. However, the advent of the intensive exploitation of agricultural land and the associated large scale land clearances during the twentieth century have, as a result of natural phosphate depletion, produced what may be described as a negative indication of human activity.

The improved knowledge of crop rotation led eventually to a lessening dependence on organic fertilisers. Better drainage changed soil chemistry and where this may have improved overall soil fertility in some cases it allowed greater exploitation of the available phosphorus by annual crop plants in what were fairly stable (in terms of soil chemistry) meadows and pasture lands. In dryer areas the clearance of hedges or the ploughing up of natural grassland led to serious soil erosion by wind (e.g. the Oklahoma dust bowl and East Anglia).

In tropical countries the clearance of rain forest vegetation, the almost exclusive sink and hence capital of available phosphorus, left the infertile laterite soils upon which nothing would grow without intensive applications of artificial phosphate fertilisers.

It is the intensive application of artificial phosphate fertilisers that has had a positive impact on anthropogenic phosphorus in modern times (see Box 2.2) and it is the persistence of soil phosphorus that makes it a suitable marker of human activity. How we might measure this is discussed in the next section.

Superphosphates

Artificial phosphate fertilisers (superphosphates) have been used for 150 years. Before their introduction agriculture relied on farm yard manure (fym) and dunging by grazing livestock. Although other sources are available and used, inorganic super phosphates synthesised from phosphorites (see above) have been the major source of agricultural phosphorus in the western hemisphere since the beginning of this century.

Organic phosphate fertilisers:	*fym, guano, bone meal and other animal by-products.*
Inorganic phosphate fertilisers:	***superphosphates**, basic slag and rock phosphate*

Super phosphates are usually applied to agricultural land in a granular form. These granules adsorb soil water. Most modern phosphate fertilisers are a compilation of various forms of calcium phosphate e.g. calcium monophosphate, calcium diphosphate and cacium triphosphate. These mobilise at different rates thus achieving a slow release and more complete uptake of the element by the crop plant. Phosphorus from the fertiliser diffuses outwards. Diffusion is very slow and is only over a short distance. E.g. even very soluble phosphoric acid may take several weeks to travel only a few centimetres (Wild, 1988, 731). In that time, unless taken up by a plant root (or other soil biota), it will interact with soil minerals or free metallic ions and become "fixed". It has been shown in laboratory experiments (Chang & Chu, 1961) that, for some clay soils, all soluble phosphates can be fixed within three hours. However, a proportion of the fixed phosphates exists for some time, possibly years (Larsen, 1971), in a potentially plant available or labile state before conversion into the non-labile and long term residual forms.

Well over 30 million tonnes of phosphate fertilisers were used world wide each year in the mid 1980s (Russell, 1988, 26). In England and Wales wheat crops, for example, receive approximately 60 kg per hectare per year (Russell, 1988,27). Crop plants take up as little as 5% of this so depletion through crop removal is negative. Since it is also the case that insignificant amounts are lost by leaching, agricultural soil is a net accumulator of phosphorus.

It has been calculated (Hamond, 1983) that a modern arable soil can accumulate approximately 18 ppm of phosphorus per year. In anthropogenic soils ancient enhancements of between 2000 and 3000 ppm are not unusual. This would equate to a superphosphate residue from a 100 - 150 years of application.

It has been estimated (Pigott *et al*, 1964) that 40% of the phosphorus content agricultural soils has been contributed by chemical fertilisers. However, modern fertilisers are applied in a uniform manner, over specific areas and within rotations. They are, therefore, unlikely to mask archaeological within-site differences. It has been suggested that sampling at greater depth (Hamond,1983) would by-pass this modern contamination altogether. See Part 3, page 115.

Box 2.2

2.6.4 THE MEASUREMENT OF PHOSPHORUS IN THE SOIL

Any known quantity of soil contains an absolute amount of phosphorus and it is reasonable to assume that, if the extraction technique is thorough, the total phosphorus content can be measured. As we have seen phosphorus is found in soils in various forms and at various degrees of bonding. The release of phosphorus from the soil requires the loosening of these bonds but, even when extraction involves the rigorous digestion of a soil in the laboratory, the completeness of this process can not be totally guaranteed. Furthermore, the evaluation of digested extracts has generally been by observing colour changes induced by the addition of an indicator (see Box 2.3) and measuring the relative intensity of the colour change against a standard solution. A technique which can only be comparative assessment and not absolute.

The "molybdenum blue" method

The "molybdenum blue" method is perhaps the most widely used of the quantitative assessments of phosphorus in soil extracts. It is sensitive and can detect even small amounts. Orthophosphate ions released by the extraction technique, in contact with an acid molybdate solution, form a phosphomolybdate complex. In the presence of a suitable reducing agent an intense blue colour develops. (The reaction was first recorded by Berzelius in 1826). The intensity of this colour reflects the quantity of phosphorus released from the sample and can be assessed accurately using colourimetric or spectrophotometric means.

There are variations to the test each determined by choice of reducing agent. Different agents will affect the sensitivity and the stability of the reaction and they are selected to meet the needs of the investigation. Ascorbic acid (Anon, 1967) is favoured for archaeological field-testing as, though less sensitive than benzidine or stannous chloride, it is more stable.

The Austrian chemist and doyen of the "spot test", Fritz Feigl, laid the foundation for what was to become a series of progressively "improved" field filter-paper tests in 1929 and not as late as the 1950s as has been suggested (Eidt, 1984, 35). Nevertheless, this "molybdenum blue" spot test was not taken up by archaeologists until the early 1960s (Gundlach, 1961).

The "vanadomolybdate yellow" method

An alternative to the "molybdenum blue" test is to omit the reducing agent and to introduce instead ammonium vanadate which reinforces the yellow colouration of the non-reduced phosphomolybdic acid i.e. by forming vanado-phosphomolybdic acid (Jackson, 1958). Though less sensitive it is even more stable and can be used on the nitric acid soil digests produced for heavy metal analysis.

Box 2.3

Arguably all extraction techniques are arbitrary. They are either assays of different fractions of the total phosphorus content of the soil or attempts at fractionation, each step of which potentially confounding the other.

In more recent years other techniques of phosphorus analysis have become available, particularly in the area of multiple element analysis, such as inductively coupled plasma (ICP) and X-ray fluorescence. The relative merits and disadvantages of these techniques are discussed in Part 3.

A. TESTING FOR PHOSPHORUS - THE EARLY YEARS

In the introduction to this Section, reference was made to the discoveries of Olaf Arrhenius who, in the 1920s, while undertaking an agronomic investigation, came to an archaeological conclusion. His prime interest had been in crop nutrition and his analytical technique was designed to evaluate plant available phosphorus which, as discussed above, is a tiny and seasonally fluctuating fraction of the total soil phosphorus. Nevertheless, his methods worked sufficiently well for him and for others to establish the use of phosphate analysis in archaeology. How this fairly crude method was adapted and "improved" over the 70 or more years since its discovery is in itself an instructive insight into the potential and pitfalls of soil analysis in archaeology

Arrhenius's procedure was to shake up soil samples in 2% citric acid thus extracting the small *available phosphorus* fraction. The supernatant solution was then subjected to the "molybdenum blue" test (See Box 2.3) and the concentration of the extracted phosphorus quantified using a colour comparator. Over the years the Swedish researcher was able to demonstrate a clear correlation between soil phosphorus and the local concentration of Mesolithic artefacts and also of medieval settlements (Arrhenius, 1929, 1934 & 1955). Arrhenius's work was taken up by the Danish archaeologist Werner Christensen using a different weak acid (1% nitric acid) but also demonstrating close association of available phosphorus with the archaeology, in this case the site of a Medieval Danish village (reference by Dauncey, 1952). This early work was not confined to Scandinavia, nor indeed to Europe. Archaeologists were able to use the technique successfully on acidic tropical soils[55] whilst investigating abandoned

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[55] I. W. Cornwall, in his *Soils for the Archaeologist*, stated quite erroneously that phosphate on conversion to free phosphoric acid by humic acids within the soil ... *if not absorbed by plants and in the*

settlements in the Far East (Castagnol, 1939 & Pendleton, 1943). Also during the war years a German researcher, W. Lorch, took up the Scandinavian pioneering work. Lorch used somewhat simplified sampling and analytical techniques similar to those of Arrhenius and Christensen and, although these were criticised as crude (Dauncey, 1952) and unperfected (Eidt, 1984, 18), his findings led him to speculate on the methodology. Lorch's initial ideas (Lorch, 1939), which remained largely theoretical, included the suggestion that phosphates of different types in the soil may indicate the presence of features, of different economies and even of the age of an archaeological site.

In the early 1950s Christensen began work at the University of Birmingham in collaboration with K.D.M. Dauncey. Together, and using a slightly more robust methodology, i.e. digestion of soils with 2N acetic acid, they demonstrated soil phosphorus associations with abandoned Medieval villages and a Roman fort in Nottinghamshire.

The first published phosphate studies in the USA were conducted at Indian burial sites in West Virginia in 1948 (Solecki, 1951) followed shortly by work on abandoned settlements in Alaska (Lutz, 1951). In both cases researchers relied on extracts of available phosphorus, but Lutz expanded his interest to cover other soil elements and associated vegetation (see Part 6). A visit by Olaf Arrhenius himself to California in 1961, ostensibly to investigate and collect soils from prehistoric sites, stimulated S. F. Cook and R. F. Heizer to take up similar investigations. It was the results of their work (Cook and Heizer, 1965) that created one of the cornerstones of research into the chemical analysis of archaeological soils.

It was realised (almost from the outset of archaeological soil-phosphorus research, *cf* Lorch, 1939) that the relatively simple techniques adopted from plant nutrition science measured only a tiny fraction of the total soil phosphorus reservoir and that, perhaps, archaeologically important anthropogenic phosphorus was not being fully evaluated. However, progress became torn between two priorities and consequently suffered. Whereas, on the one hand some researchers saw a more complete laboratory analysis as the way forward, others saw such procedures as laborious, time consuming and (perhaps

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absence of sufficient bases to refix it as an insoluble, is leached out and lost in the drainage (Cornwall, 1958, 195) . He compounded this with a further statement ... *acid soils, deficient in bases (pH<5.6), have no power to fix phosphate, which will be rapidly leached out.* Work as far back as the 1940s (see above) had already demonstrated that this was not the case.

more importantly) out of the direct control of field archaeologists. Thus a great deal of time and effort was devoted over the years to the development of a satisfactory field test.

In the early 1950s the chemist Allard Johnson assisted Stuart Pigott in his investigations into a chambered cairn near Inverness by offering to analyse samples of soil from the site. Johnson used the weak acid (in this case 0.5 N acetic acid) method but was concerned at the unreliability of his results (Johnson, 1956). He put the failure down to the acid nature of the soils of Highland Britain. He switched to a more rigorous methodology of digesting the soil in a mixture of concentrated nitric and sulphuric acids, a method adapted from a crop nutrition analytical procedure for the evaluation of "total phosphoric acid" .... which no doubt dislodged a proportion of the organic and inorganic fixed phosphorus.

Within a year of Johnson publishing his results two American soil scientists announced an accessible procedure whereby variously fixed soil phosphorus could be analysed "species" by "species" (Chang and Jackson, 1958). Although offering a golden opportunity to archaeologists to further Lorch's theories, the technique was not taken up immediately as what seemed an easier option had presented itself.

B. TESTING FOR PHOSPHORUS - IN THE FIELD

In the immediate pre-war years, Walter Lorch developed and applied a simple archaeological field test for soil phosphorus, using it extensively during his researches. The methodology, based on the partial extraction of inorganic phosphorus using a weak acid, was not widely adopted. It was criticised as being too crude and, for Lorch's bold interpretative theories, insufficiently accurate (Dauncey, 1952). In 1961, H. Gundlach modified Feigl's molybdenum blue spot-test technique (see Box 2.3) by replacing the reducing agent (benzidine) with ascorbic acid and using it directly on a soil sample placed on a filter paper. The result was a new simple, but quantifiable field-test for soil phosphorus (Gundlach, 1961). This technique was picked up and systematically modified by archaeologists; first by Schwarz (1967), then Abt (1968), followed by Sieveking (1973), Eidt (1973 &1977) and eventually Craddock (1985). However, the general conclusion (Keely, 1983; Hamond, 1983; Gurney, 1985) has been that field-testing as a technique is somewhat rough and ready. Although adequate for locating

areas of activity, it requires, if a deeper interpretation of the result is sought, the back-up of more precise laboratory analysis.

C. TESTING FOR PHOSPHORUS - IN THE LABORATORY

Almost all the phosphorus in the soil is fixed, immobile and unavailable to plants. Such is the fate of phosphorus whether it is of geological or biological origin; whether it derives from the inadvertent waste products of human settlements or from the deliberate application of artificial fertilisers. However, if within a suspected zone of past human activity the background levels of soil phosphorus have been enhanced then a comparison of total soil phosphorus measurements over and surrounding this area may well identify the site. Measurements of total phosphorus are, therefore, justifiable archaeologically and have indeed been widely used (e.g. Johnson, 1956; Mattingly & Williams, 1962; Gardner & Walsh, 1966; McCawley & McKerrell, 1972; Pare & Nebelsick, 1981; Balaam & Porter, 1982; Hamond, 1983).

Total phosphorus: To release this strongly bound phosphorus into solution is a two stage procedure. At first the organic element has to be mineralised. This is usually achieved by a process of oxidation, either by ignition or by using a powerful oxidising agent (such as perchloric or nitric acid). The mineralised phosphorus has then to be dissolved so the solution can be treated with an indicator and a colorimetric assessment made. Boiling with perchloric acid (a hazardous operation) is a very effective method but the somewhat safer use of nitric acid[55] does give an adequate assay. Alternatively the soil is fused at high temperature with sodium carbonate before dissolving in acid. Two American workers (Dick & Tabatai, 1977) eventually introduced a safe and effective technique using sodium hypobromite which has been used by archaeologists (E.g. Balaam & Porter, 1982).

Inorganic and organic soil phosphorus: It is probable that the tendency over the years of early investigators to use stronger re-agents to extract "available" soil phosphorus (see Table 10.1) resulted in the freeing up some of the non-labile *inorganic phosphorus*. It was soon found that evaluations of a greater proportion of this fixed phosphorus gave less variable and more quantifiable results. Methods using stronger re-agents, higher

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[55] The use of oxidising acids, such as concentrated nitric acid, can be incompatible with the reductive molybdate blue indicator - see Box 2.3, page 95.

temperatures and /or longer periods of digestion became more widespread among archaeologists, particularly from the 1970s on (Mauritzen, 1969; Provan, 1971; Sieveking, 1973; Clark,1977; Nuñez, 1978; Gurney & Craddock, 1981; Edwards, 1983; Craddock, 1984). Even field testing techniques for inorganic phosphorus were devised (Hughes, 1976; Hassan, 1981) and used with satisfactory if not as quantitatively accurate results (Gurney, 1985, 3).

In soil, o*rganic phosphorus* can constitute as much as 70% of the total. It is usually evaluated by deducting the inorganic component from total (the organic being subsequently mineralised by an oxidative process, i.e. the *ignition-acid* extraction). Being able to distinguish between the available, inorganic and organic phosphorus in the soil is a simple form of fractionation and was first incorporated into an archaeological study in this country as part of an investigation into a fossilised soil horizon under a Roman amphitheatre in Wiltshire (Mattingly & Williams, 1962). However, research into the archaeological potential use to archaeologists of phosphorus fractionation was undertaken during the 1970s and, for the most part in the USA. This research was, surprisingly, confined only to the inorganic components of the soil.

Fractionation of soil phosphorus: From Lorch onwards there was the realisation that a fuller knowledge of the types (chemical species) of phosphorus in the soil might reveal more about the site under investigation. Work in the late 1950's referred to above (Chang & Jackson, 1957 & 1958) on the fate of phosphate fertilisers provided archaeologists with the basis for a sequential extraction technique (fractionation – see Table 2.42).

Table 2.42 Fractionation of inorganic soil phosphorus (after Chang *et al*, 1958)

Extract	Process
aluminium phosphate	*room temperature, neutral 0.5N NH_4F*
iron phosphate	*room temperature 0.1N NaOH*
calcium phosphate	*room temperature 0.1N H_2SO_4*
occluded (reductant soluble) iron phosphate	*citrate-dithionate reagent*
occluded aluminium phosphate	*repeat room temperature neutral 0.5N NH_4F*

Information derived from Chang & Jackson, 1958

The authors argued that soluble phosphates were fixed initially as aluminium phosphate (or calcium phosphate in lime rich soils) and that these were translated, by the various processes of soil chemistry, into even less available forms, i.e. iron phosphate and occluded phosphates. The latter, it was suggested, taking centuries to form. Hence, the argument has been made for dating soils (and the associated site) through fractionation of inorganic soil phosphorus. The Chang & Jackson technique was adopted by archaeologists and, over the years, modified to suite their needs (see Table 2.43). (Eidt & Woods, 1974; Eidt, 1977 &1984; Woods, 1977) .

Table 2.43 Fractionation of inorganic soil phosphorus (after Eidt, 1984))

Fraction	Phosphorus 'species'	Reagent (i.e. combinations of)
Fraction I	Easily extractable phosphorus	sodium hydroxide, sodium citrate, sodium bicarbonate
Fraction II	Tightly bound or occluded phosphorus	sodium citrate, sodium bicarbonate, sodium dithionite
Fraction III	Calcium phosphate and Apatite	hydrochloric acid

Information derived from Eidt, 1977.

Fractionation of soil phosphorus is an involved and time consuming process and, despite its potential as an archaeological diagnostic tool, has not found universal popularity outside of America.

2.6.5 IDENTIFYING ANTHROPOGENIC PHOSPHORUS

Although it may be relatively simple to demonstrate an increase in the total or even specific fractions of phosphorus in the soils of an ancient settlement, there are further questions an archaeologist might wish to ask. First, what precise part of this phosphorus is associated with human beings and, further, what can this information tell us about the sort of activities that have taken place or when they took place?

During the 1920s, Olaf Arrhenius, as well as demonstrating a close correlation between "phosphoric acid" (cf. available phosphorus) and sites of past occupation, also confirmed that the highest concentrations of phosphorus were always associated with the focal centres of the settlements (Arrhenius, 1929). This work inspired Werner Christensen to carry out a detailed study on the Danish medieval village of Stokkerup, which had been destroyed in the early seventeenth century. He was able to show an association between available soil phosphorus and different ***zones*** of activity (as reported in Dauncey, 1952 – see Table 2.44).

Table 2.44 Phosphorus association with various zones of activity (after Dauncey, 1952)

zone	*available phosphorus mg/kg*
village area	1000 - 3400
adjoining cultivated area	100
outside the settlement	50

Christensen also argued that, based on the evidence of available soil phosphorus levels, the occupation of the Viking ring-fort at Trelleborg was relatively short-lived compared with a that of a local village (*ibid*). In a study of Swedish medieval villages (Arrhenius, 1955), Arrhenius attempted to show a correlation between the level of available soil phosphorus and the age of settlements (determined by place-names). He was unsuccessful, somewhat boldly attributing his failure to the unreliability of place-name evidence (*ibid*).

However, it was Walter Lorch, in 1939, who first suggested that *different types* of soil phosphorus might indicate the presence of features, provide the evidence of different economies and even enable the identification of the age of an archaeological site. Unfortunately his work remained largely theoretical. A practical fractionation technique for archaeologists did not arrive until the late 1950s (see above) and it was not until the work of two other Americans, R. C. Eidt and W. I. Woods in the 1970s, that any attempt was made to advance Lorch's theories. This initiative in the USA was stimulated by a boom in federal funding of archaeological research during the Bicentennial celebrations.

Eidt's premise (Eidt, 1977, 1984) was that it was within the inorganic component of soil phosphorus (organic phosphorus is relegated for some reason[56]) that the anthropogenic factor could be evaluated. He called this *settlement phosphorus* (P_{set}). His three fraction (see 5.3.3 above) was, in effect an assay of total inorganic phosphorus. It was from the relative ratios of the P_{set} fractions that Eidt proposed that site function and land use could be determined; that soil profile samples could reveal changes in function and use over time; and that a sequential chronology might also be revealed. However, soil phosphorus ***assaying*** as a technique remains problematical and consequently undeveloped. Soil phosphorus ***prospection***, on the other hand, has progressed over the years.

[56] Perhaps it was felt that organic matter decomposes, how ever slowly, and the released phosphorus would eventually become fixed in and inorganic form. If so, the time scale would be very long.

2.6.6 PHOSPHORUS SURVEYING IN ARCHAEOLOGY

A. LARGE SCALE PROSPECTION

The early European surveyors (Arrhenius, Lorch, Christensen etc.) sampled wide areas, sometimes kilometres across in systematic grids. Samples were removed from the surface layers and sometimes from deeper soil cores. The surveys were a true or "active" (Bethell & Máté, 1989) prospection being aimed at the discovery of unknown sites. Over the years they were more often "passive" and used to explore the extent of archaeologically confirmed sites.

Today, used in conjunction with geo-prospection and aerial surveys phosphorus surveys are once again being seen as primary tools, particularly on sites where there may be little to excavate. There is, however, often a confusion over the application and interpretation of geophysical prospection and geochemical prospection. The former, particularly with gradiometry and resistivity, is usually targeted at archaeological features (e.g. buried ditches, house platforms, etc.), whereas a phosphate survey aims at revealing archaeological activity, a "halo" (Bintliff *et al*, 1990) or "pen-umbra" (Hamond, 1983) of contamination around a settlement. In some cases surveys can identify radiating zones of enhancement that can be plotted as contour maps and associated with the relative intensity of human activity.

Statistical techniques to elucidate these zones have been developed (Buck & Cavanagh, 1988, 1992 and Cavanagh *et al*,1988). Nevertheless, the temptation to apply analysis of soil phosphorus to localised archaeological features has proved irresistible.

B. INTENSIVE PROSPECTION

The first applications of intensive phosphate prospection were for the interpretation of soil silhouettes, dark stains in the soil most often associated with inhumations (Solecki, 1951; Johnson, 1956; Biek, 1957; and later Barker *et al*, 1975, Keely, 1981 and Bethell *et al*,1989). See Box 2.4.

Phosphorus and bones

One of the richest sources of anthropogenic phosphorus is bone and it would only be expected to associate enhanced levels of soil phosphorus with charnel grounds, carcass pits and inhumations, especially where fragments of bone survive and are included within the soil sample taken (Keeley *et al*, 1977). However, a not uncommon feature associated with inhumations, where no part of the skeleton has survived, are stains in the soil. These often (but not always) take on the outline of the body and are known as **"silhouettes"**.

One of the first to subject a silhouette to chemical analysis was Allard Johnson in 1954 while assisting Stuart Pigott in his excavation of the chambered cairns of Corrimony near Inverness, Scotland. His initial assessment of available phosphorus using a weak acid was inconclusive, but total phosphorus assessments revealed a close association. Johnson calculated that 50% of the estimated body-mass phosphorus of the interred individual was contained in the soil within 15cm of the stain (Johnson, 1956). However, L. Biek carrying out a similar investigation in 1957 into the silhouette found in a barrow at Bishops Waltham found no conclusive association of total phosphorus with the body stain (Biek, 1957). He did find enhance levels of manganese. In 1968 a large number of silhouettes were found at a multi-period site at Mucking, Essex (Jones, 1968). Subsequent analysis of silhouette soil from an Anglo-Saxon grave on the site picked up elevated levels of soil phosphorus, although on calculation they constituted only 4% of the estimated body-mass phosphorus (Werner & Hughes, 1971). The analysis also revealed a significant enhancement of manganese in the stained areas. Further investigations were carried out on these soil samples and it was found that phosphorus enhancement was localised and associated with surviving fragments of bone whereas the manganese was clearly related to the volume of stained soil (Keeley *et al*, 1977). These workers postulated that the phenomenon might be connected with enhanced manganese mobility induced by soluble phosphates (phosphoric acid) derived from the body, or by the concentration of manganese by microbial action soon after inhumation. The latter pathway has much to recommend it. Manganese mobility only happens if the Mn^{++++} ion is reduced to Mn^{++} and then re-oxidised to Mn^{++++} to fix it again. This process is related to microbial reduction and as such is dependent on organic matter (the body) being available for aerobic decomposition. The net result is the precipitation of a purple black oxide (manganese di-oxide) which creates the stain. However, more recent work at Sutton Hoo (Bethell *et al*, 1989) used ICP spectrometry to examine 131 grave fill samples. Enhanced phosphorus levels were associated with the inhumations but analysis failed to confirm any differential manganese distribution. It is clear the soil chemistry associated with inhumations is complex and variable. Whatever the logic in applying soil phosphorus analysis to detect places of burial or bone disposal. in some cases it would be more profitable to test for derivative elements.

Box 2.4

Later uses were generally in conjunction with on-going excavation and applied to exposed ancient surfaces in the assumption that the soil chemistry of this buried landscape had been preserved along with features and artefacts. To an extent this was true but it did overlook the long term dynamic nature of soil, especially bioturbation, and the possibility that the past might be better preserved on the surface.

C. VERTICAL PROFILING

Archaeology, like geology, is conceptually stratigraphic. Usually (but not always) to descend through the soil is to regress into the past. Vertical profiling of phosphorus through soil coring, or from an excavation, enables archaeologist to identify changes in human activity over time. Graphs of these profiles are variable in character but generally "bulge" at the point of archaeological activity and diminish as the core approaches parent geology or "natural". Almost all the graphs omit the top 10cm - 30cm. This is because there is a (mis)conception that the upper surfaces of the soil have either been archaeologically destroyed through erosion or cultivation or irrevocably contaminated by modern fertilisers or domestic animals. The theory and methodology of soil sampling is discussed in Part 3.

D. INDIRECT ASSESSMENT

Within the discipline of pollution science the use of indicator plants to evaluate soil contamination is well established, and has been used by archaeologists at least from the early 1950s (see Box 2.5).

Phosphorus and Plants

There has been long folk-association of vigorous plant growth, particularly of nettles and elder, with sites of past human activities. Old middens, stockyards, around feeding troughs, along road sides and in gateways: even on the sites of Roman camps and Iron Age hill forts. In 1883 the German botanist, Hans Molisch, after testing sap, ascribed this vigour to a peculiarly high demand for nitrates.

In 1951 H. Lutz, an American archaeologist described the location of deserted Indian villages in Alaska simply on the basis of the associated "luxuriant" and "dark green" foliage, particularly the "nitrophilous" stinging nettle. Lutz notes, however, that the most obvious alteration to the soil chemistry was a 50-fold increase in (available) phosphorus in comparison with off-site soils.

It was not until the mid 1960s that two British scientists identified the key nutrient to abundant nettle growth not as nitrogen but phosphorus (Pigott & Taylor, 1964).

Box 2.5

2.6.7 CRITICISMS OF THE TECHNIQUE AND PROBLEMS OF INTERPRETATION

The problems associated with the prospection and assay of archaeologically related soil elements are discussed more fully in Part 3. However, there are some problems and criticisms peculiar to soil phosphorus analysis that are worth addressing here.

A. ANALYTICAL PROCEDURE

It is possible, once obtaining a sample of soil, to evaluate quite accurately the total amount of phosphorus it contains by using a rigorous acid-oxidation extraction technique. For reasons of convenience (and safety) such methods have not been applied widely. The methodologies used by archaeologists have been adapted largely from those used by crop scientists whose main concerns have been to estimate plant available phosphorus and to understand the chemistry of soil-plant relations. Over the years archaeologists have learned that the more robust the technique, the more phosphorus can be extracted. And, by and large, the more thorough the extraction the more reliable the relationship between soil phosphorus and archaeology. Unfortunately, the evolutionary nature of the these techniques has meant that it is difficult to find any consistent group of workers that have followed precisely the same analytical procedure (see Table 2.45).

Table 2. 45 Methodologies of phosphorus extraction from soil used by archaeologists.

paper	date	analysis	type	method
Dyer*	1894	laboratory	available	1% citric acid
Hughes*	1911	laboratory	available	1% citric acid (?)
Arrhenius	1929	laboratory	available	2% citric acid
Schnell	1932	laboratory	available	2% citric acid
Christensen	1935	laboratory	available	1% nitric acid
Bagge	1937	laboratory	available	1% nitric acid
Lorsch	1939	field	available	weak acid (?)
Johnson *et al*	1949	laboratory	total	conc. nitric and sulphuric acid
Dauncey	1952	laboratory	available	2N acetic acid
Gundlach	1961	field	partial	conc. nitric acid & ascorbic acid i.e. the filter paper method (after Feigl)
Schwarz	1967	field	partial	conc. nitric acid i.e. a *modified* filter paper method
Provan	1972	laboratory	total	2N hydrochloric acid @ 100°C.
Mc Cawley *et al*	1972	field	total	yellow phosphomolybdovanadic acid (Stanton 1966)
Mc Cawley *et al*	1972	field	partial	conc. nitric acid (after Schwarz)
Sieveking	1973	laboratory	partial	2N hydrochloric acid @ room temperature
Eidt	1973	field	partial	conc. hydrochloric acid i.e. a further modification of the filter paper method
Eidt	1977	field	partial	conc. hydrochloric acid i.e. a modification of Eidt's earlier method
Alexander *et al*	1978	field	partial	conc. nitric acid (after Schwarz)
Griffith	1980	laboratory	partial	1*M* neutral ammonium acetate extract. I.e. Olsen & Dean (1965)
Edwards	1983	laboratory	total	nitric, hydrochloric & perchloric acid
Hamond	1983	laboratory	total	ignition @ 550°C followed by 1N HCl
Hamond	1983	field	partial	
Conway	1983	laboratory	total	perchloric acid @ 200°C
Craddock *et al*	1985	field	partial	hydrochloric acid @ 100°C
Crowther	1997	laboratory	total	alkaline oxidation with NaOBr (Dick and Tabatabai ,1977)

* not archaeologists

Even within the limitations of the physical and chemical consistency of different soils inter-site comparisons have been virtually impossible.

B. FRACTIONATION

The same criticism can be directed at soil phosphorus fractionation. Dauncey was critical (see above) from the outset of Lorch's claims to be able to identify characteristic profiles (Dauncey, 1952). What Lorch was doing was not strictly phosphorus fractionation, but it was his work that lay behind that of Eidt in the 1970s. Soil phosphorus is resident in the soil either in an organic or in an inorganic form. A tiny proportion of this phosphorus is in solution or is labile. To take, as Eidt did, inorganic soil phosphorus and subject it to a particular progressive process of extraction will inevitably produce quantifiable fractions. But whatever the elegance of the theory and the potential for correlating these fractions with past economies or even site chronology, these techniques remain artificial and arbitrary. Philip Bethell and Ian Máté were more forthright in their dismissal of Eidt's proposals and with regard to phosphorus considered it ".... *unlikely that complex fractionations will ever be a standard part of archaeology*" Bethell & Máté, 1989). The authors held out more hope for organic/inorganic comparisons subject to the establishment of a sufficient database and were more convinced that a multi-element approach was the way forward.

Further development of soil phosphorus analysis as a diagnostic technique will depend on the emergence of a standardised and site-comparable methodology, and on the integration of this methodology with a wider soil diagnostic approach which should include among other things the evaluation of heavy metals and organic carbon.

2.7 ANTHROPOGENIC RESIDUES – A SUMMARY

Human activities produce prodigious amounts of waste that are largely organic. Most of this waste is lost as carbon dioxide or water, or through the leaching of the more labile decomposition products. An accumulating proportion of immobile residues can, however, survive for hundreds, if not thousands, of years. These anthropogenic residues remain clearly detectable in the soil often despite modern industrial contamination or agricultural practices. Hence soil evaluations of, for example, organic carbon, phosphorus or heavy metals may be used as a measure of past human activities.

In the above Sections the sources, accumulation and survival of human soil residues have been described and consideration has been given to the distinction of these anthropogenic deposits from those of a non-anthropogenic origin. It is now necessary to consider how the archaeological soil chemistry might be measured.

Part Three : Methodology

INTRODUCTION

This part of the dissertation discusses the methodology and underlying principles of site selection, sampling and laboratory analysis. This is followed by an explanation of how the results are presented and the statistical procedures applied to these data.

3.1 SELECTION OF SITES

It was decided at the outset that investigations were more likely to produce unambiguous results if the sites selected were free of the worst of modern pollution and uncomplicated by multi-period occupation and recent activity. This required locations away from large conurbations, major roads and urban industrial complexes, on less intensive arable land with a predominance of undisturbed pasture; and on deeper, relatively unworked lowland alluvial soils with a neutral pH. A preference was made for sites that promised to be single-period modest rural-settlements. In order to demonstrate the potential of the technique sites were chosen where the surviving archaeology was not obvious and/or where the application of conventional archaeological techniques was limited or inhibited. Such sites would be located by indicative field names or unusual field configuration. In practice, of the twelve studies presented here, in attempting to meet these ideal requirements, there were inevitable compromises and a degree of opportunism (see Part 4).

Initially the number of sites was to be more limited, but interest in the technique expressed by other archaeologists at the universities of Bristol and Exeter, and by independent researchers, led to opportunities hard to refuse. In the event, the number of sites (12) and their component evaluations (19) became almost unmanageable. Indeed, a further five sites (six evaluations) had to be abandoned because of a time limit on laboratory access.

Full details of the sites investigated are presented in Part Four

3.2 SAMPLING

There is an apocryphal story of the amateur ichthyologist who, when asked to estimate the number of fish in the sea, reported that there were a great number, that they were mostly herrings and none were smaller than six inches in length. We, of course, know better. In any sampling exercise one must take into account where the net is thrown, over how wide an area, how often and to what depth. It is also wise to take into account the size of the mesh. Soil sampling is in many ways similar, although the questions being asked in this case are different. In the following investigations the population being sampled (e.g. the distribution of heavy metals within a geographic area of surface soil) is not dynamic like a wandering shoal of fish. Small settlements, their associated areas of activity and the residues they produce are fixed and (relatively) permanent. The question is not of how much the overall landscape has changed but how localised changes relate to foci of past human activity.

Location and extent of the sampling area:

None of the areas chosen for sampling in this study were selected randomly. They are either centred on or close to known archaeology; a previously excavated feature, an earthwork, a scatter of pottery sherds, patterns revealed by aerial photography or geo-physical surveying; or they encompass an area suggested by historical information, such as a field name.

Whereas it might not be a problem in deciding the location of a soil survey, it becomes less clear-cut when deciding upon the extent of the sampling area. For most archaeological surveys it is seldom considered necessary to define the unaltered environment in which the current archaeological evidence lies. This is understandable as artificially altered environments are often quickly recognisable to the trained eye even if elucidation requires some recourse to technology such as geo-physical surveying. Changes to the landscape as the result of agricultural practice and land organisation can also be fairly obvious, but when archaeology is applied to the chemistry of the soil the changes attributable to human activity become clear only when contrasted with the unaltered environment. It is therefore necessary to extend the sampling area beyond the immediate focus of archaeological interest. In the following studies a landscape wider than the known zone of past activity, fields adjoining the specific field under investigation, the rest of the field in which the earthwork sits, or, at the very least, an extension beyond the known boundary of the site have been included in the sample area.

An insurmountable problem with this approach is that it cannot be assumed that any area adjoining the study site is unaltered, even relatively. In a landscape that has been populated for many millennia, it is improbable that there are any soils at all that have not been altered by man. Another problem of wider landscape studies is the inevitable introduction of increasingly unmanageable variables from the macro influences of geology, soil type (Crowther, 1997), agricultural practice and modern human activity in general (see Part 5, page 223).

Size, number and frequency of sampling:

Soils were collected at intersections of sampling grids set at 5m, 10m, 15m, 20m, 50m or 100m spacings. Approximately 500 - 1000g of soil were removed to a vertical depth of 15 cm from each sampling point and placed in sealable polythene bags. Samples were taken with a stainless steel trowel which was wiped clean between each operation. At one site the same grid was re-sampled after a two year interval.

The appropriateness of any particular sampling procedure is often a matter of debate, none more so than the vexed question of sample size. Kahn & Northcliff (1982) studied the spatial variability of the concentrations of readily extractable iron, manganese, copper and zinc in three 1 ha grids in close proximity within a single soil series (see Table 3.1). The authors, using statistical methods, estimated that the following number of samples were required to reach predetermined levels of precision.

Table 3.1 Sample sizes required for estimates within 5%, 10% and 20% of the true mean at 0.05 significance level, by grid (Kahn & Northcliff, 1982).

Accuracy	Grid	Iron	Manganese	Copper	Zinc
± 5%	1	175	325	37	53
	2	645	569	28	130
	3	115	89	33	55
± 10%	1	45	82	10	14
	2	162	143	8	34
	3	30	23	9	15
± 20%	1	12	22	4	5
	2	42	37	3	10
	3	9	7	3	5

Table 3.2 Sample sizes required for estimates within 2.5%, 5%, 10% and 20% of the true mean at 0.05 significance level by soil series (Kahn & Northcliff, 1982).

Accuracy	Iron	Manganese	Copper	Zinc
± 2.5%	1244	1484	256	364
± 5%	312	372	65	92
± 10%	79	94	17	24
± 20%	21	25	5	7

They found large contrasts between the grids and between elements (see Table 3.2). Iron and manganese showed greatest spatial variability and hence required the largest sample sizes; copper and zinc proved less spatially variable. On the basis of these findings at least 100 samples per hectare (i.e. a 10m grid) are required to achieve an accuracy of ± 5%. Sampling on a 20m grid would increase this error to ± 10%.

However, the findings of Kahn & Northcliff do not altogether apply to the situation found in the studies reported here. Soil analyses in this research are not seeking to assess critical levels of 'available' plant nutrients, but to make a more robust evaluation of the 'total' heavy metal content. These evaluations are inevitably estimated concentrations. They are not absolute and their use is comparative. Although repeatability is a fundamental scientific requisite[57], it is important to note that in this case the search is not for an overall field-mean upon which to base an agronomic decision, but an assessment of variation within the test area. Apart from manganese, all the metals tested were relatively soil stable.

In any form of prospection an aim will be to cast the net as widely as is practicable in order to pick up some indication of where to intensify the search. At Hamm Farm (see Part 4, page 150) an area of approximately 60 ha was sampled on a 50m and a 100m grid (which in practice worked out at 3.8 and 1.7 samples per ha respectively) in an attempt to do just this. In such a process the risks of missing small areas of soil enhancement within the grid square increases as do the effects of the macro-influences referred to above. A corollary of this is to look at intense sampling and to see whether inherent soil variations confuse the pattern if examined too closely. In Church Field, Shapwick, approximately 2 ha were sampled at 5m intervals (441 samples per ha) to test this. The exercise was also an attempt to correlate more closely heavy metal concentrations with archaeological features.

[57] See below - Section E (a) Data Analysis

3.2.3. Depth of sampling:

As stated above, all the samples for this research were taken from the surface, below the turf line but within the plough soil. An obvious question arises. Why should surface soil in which, on agricultural land, any archaeological features have been destroyed, reveal reliable evidence about previous human activity? Why not sample below the plough zone in an undisturbed horizon?

The choice of topsoil sampling was, in the first place, a practical one. To obtain samples from the a lower soil profile would have required augering and on the clay-silt soils of the Somerset moors, for example, this would have been an onerous task and would have significantly reduced the number of samples taken.

That being said, there is an unavoidable logic in taking samples from the archaeological horizon. However, when initially prospecting for a site, unless a series of test pits is dug, this horizon is unknown. On the old flood plains of Somerset, for example, the level of Roman occupation can be buried under a few centimetres or several metres of marine silt.

A recent study (Crowther, 1997) has illustrated the problems that can arise with vertical or profile sampling (in this case for phosphorus). Crowther observed that certain circumstances gave rise to inconsistent results. These included eroded upland soils where the depth over the parent geology was inconsistent; heterogeneous (e.g. agriculturally unworked) soils where there were spatial variations in the retention-capacity of the soil; where the archaeological horizon was not at a constant depth; and where there had been recent phosphate inputs from fertilisers, manure, grazing animals, etc. Crowther, nevertheless, advised some soil depth evaluation prior to undertaking a spatial survey. He also advocated supplementing phosphorus assessments with loss-on-ignition evaluation, arguing that the latter could highlight variability in the mineralisation of phosphorus and, potentially, be a surrogate measure of soil depth. There is, however, the situation in which the archaeology survives only in the top soil. Work on a multi-period site at Maxey near Peterborough (Gurney & Craddock, 1981) demonstrated that surface concentrations of phosphorus provided evidence of features and activities that would have been destroyed and lost if the usual practice of topsoil stripping had been employed. Within the studies presented in this dissertation, excavations subsequent to soil analysis in Church Field, Shapwick showed that many of the anticipated archaeological features had been destroyed by the plough.

Apart from the glacially derived fluvial deposits of the Kirkdale meadows (see Part 4, page 169), all the samples examined in this research were taken from neutral to slightly

alkaline, lowland, alluvial soils of reasonable or, at least, consistent depth and all were in agricultural use. Most of these soils are under grass, some have been so for much of their history. All have been turned by the plough at some time, some regularly and quite recently. It is argued in this thesis that the top 15 cm of such soils are suitable for geo-chemical prospecting on the basis of their *homogeneity* and their ability to act as archaeological *accumulators*.

3.2.4. Vertical homogeneity of top soil and effects of modern agricultural supplements:

Soils that are regularly worked by the plough, harrow or spade become, over time, vertically mixed and, in this soil zone at least, Crowther's concerns about spatial variations in the retention-capacity of the soil are minimised. The homogeneity of the plough soil effectively reduces any natural between-sample variation and enables a more consistent analytical result. The question of lateral movement of soil is addressed below. In land under long term grass, where soil is cultivated less frequently, there are other homogenising factors at work and these too are discussed below.

The effect of synthetic fertiliser (and other) additions to intensively farmed arable land of eventually obscuring any residual indication of past settlement has been discussed in the previous section (see Part 2, pages 81 & 94). In the case of phosphorus, for example, elevating the concentration to a level comparable with those typical of an ancient settlement would take hundreds of years (Chang *et al*, 1961; Hamond, 1983). Even then, it is probable that the differential between sites of past activity and background soils would be maintained for a very long time. Other modern surface contaminants such regular and prolonged deposits of animal faeces have been shown to have a surprisingly minimal effect (Walker, 1992).

3.2.5 Soil as an archaeological accumulator:

As well as being a homogeneous medium, the top soil also accumulates anthropogenic residues that are brought to the surface from the buried archaeological horizon. Three such mechanisms of residue redistribution are put forward; namely erosion, bioturbation and plant translocation. The example of Maxey (Gurney *et al*, 1981 - see above) adequately demonstrated that the archaeological evidence of heavily eroded sites may have been reduced to nothing more than surface accumulations of (in this case) phosphorus. The activity of soil fauna, particularly those that work vertically within the soil profile, can relocate buried residues on the surface. In undisturbed grassland,

earthworm populations can process (consume and excrete) 90 tonnes of soil per hectare each year (White, 1997, 44). Work at Rothamsted Experimental Station (Wild, 1988, 523), has recorded an annual addition of 0.5% - 6% to the top 10cm of soil by deep burrowing earthworms which could amount to as much as 6 cm over ten years Craddock (1984) at the Cat's Water site in Fengate, picked up phosphorus concentrations from an Iron Age settlement buried under 1.5m of alluvial clay. This was attributed to earthworm activity. Pigott & Taylor, 1964, make special reference to earthworms and the redistribution of phosphorus. There are many other soil organisms (millipedes, slugs, enchytraeid and nematode worms) and burrowing animals (moles, badgers, foxes etc) that will disturb buried soil profiles.

Plants take up soluble mineral salts from the soil and transfer them to their stems, leaves or even retain them in their roots. These salts are not always required plant-nutrients but are, nonetheless, passively adsorbed. The trace elements within these minerals are returned to the surface either in leaf drip or as fallen leaves, stems and branches, or to the soil in decayed roots. This dead vegetation is subject to the varied processes of a wide range of soil organisms (Wild, 1988). Many of the trace elements from these sources are held in a stable association with organic matter and consequently (in terms of total concentration, but not necessarily as available plant nutrients) enrich the surface layers of the soil. As early as 1952 the archaeologist K. D. M. Dauncey commented, "*The retention of phosphoric acid over long periods is partly due to its use and re-deposition by plants, but chiefly to its high resistance to leaching or similar movements*". It is by the mechanisms described above that buried anthropogenic deposits are returned to the surface where they accumulate.

3.2.6. Soil drift:

There has been a long debate on the relationship between surface finds and the archaeology that may or may not underlie them. Of great concern has been the displacement of pottery scatters by the process of soil cultivation. Lambrick (1980) argued the conventional belief that, under normal cultivation practices and on level ground, pottery and rubble scatters generally remain concentrated in their original positions. Yorston *et al* (1990) undertook a simulation of the effects cultivation on artefact displacement. The results were not conclusive but the authors argued against the complacency of those workers that dismissed any such displacement as minimal and that the use of sophisticated analytical techniques without proper consideration of all the variables could be misguided. They argued against any concept of equilibrium, that the

spread of artefacts would continue indefinitely as long as the disturbing influences were present. Specifically, the simulation demonstrated that point concentrations of artefacts are dispersed symmetrically, that annular (ring) distributions lose definition and that sampling strategies are critical if artificial patterns are not to be created.

The primary reason that farmers cultivate their land is to produce a soil tilth suitable for sowing a crop, although soil cultivation is also practised as part of weed control, green manuring and to facilitate drainage. Plough depths vary according to the operation, the soil type and the soil conditions but are usually set between 12.5cm and 17.5cm (Nicholson, 1980). In seed bed preparation, ploughing alone is seldom sufficient and yet, on some lighter or thinner soils, the plough may never be used at all. Most modern and all ancient ploughs have their mouldboards[58] fixed to one side and will throw the ploughsoil one way, usually to the right. In a simplistic model, passes of the plough up and down a field would create ridges where soil from two opposing passes is turned inwards. In a technique called *ploughing in lands* smaller areas (15m to 30m wide – Nicholson, 1980) are ploughed in passes several plough-widths apart in a shifting figure of eight. This effectively leaves "lands" of several plough-widths about a central ridge of soil and separated by a clear furrow. It is not difficult to see medieval farmers, who required sufficient space to turn their oxen, cultivated their allocated strips in this fashion. Indeed it even suggests that the not untypical medieval practice of allocating widely separated strips to an individual may have had something to do with the practicalities of cultivation. Anyone who has perused aerial photographs of farmland will be familiar with the "St. Andrew's Cross" or "envelope" pattern associated with ploughed land which is created by the more widely practised technique of *square ploughing*. This is ploughing in four directions (in rectilinear fields) in parallel with the hedgerow. The plough is usually lifted at each turn and (to avoid double ploughing) the unploughed diagonals finished off last. Square ploughing starts from the centre (the soil is shifted inwards) or from the headland (the soil is shifted outwards).

Inevitably ploughing will cause lateral displacement of the soil but this is of no practical advantage to the farmer[59] who neither requires his plough soil heaped in the centre of the field nor piled high on the headland. It is normal farming practice to vary ploughing procedure at subsequent cultivations. Either the orientation or position of the plough

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[58] Prior to the introduction of the mouldboard, possibly during the Roman period, ploughs (or more properly ards) did not turn the soil and any lateral movement of soil was insignificant. the modern reversible plough can, in effect, place the mouldboard on the left or the right.

line or (in the case of square ploughing) the starting point is altered. As stated above, ploughing (where it is practised) is only part of the cultivation process. To a greater or lesser degree ploughland is harrowed, cultivated or rolled to produce the required seedbed. On relatively level arable land the lateral movement of soil year in year out would be (except perhaps on the most intensively worked land) insufficient to obscure discrete areas of anthropogenic activity although some gradual blurring of the edges is inevitable. Yorston *et al* (1990) demonstrated how difficult it was to model the dispersal of artefacts even at a basic level and that at every site investigated the parameters would need to be reset. But the factors that can influence the movement of a pottery fragment or a piece of rubble, such as impact with a share or tine that can send small stones flying through the air, or the dragging ability of a stroil-choked harrow, do not necessarily equate to a comparable movement of the soil itself (see Marter, 1997). McGrath (1987 and McGrath *et al* 1989), however, noted some lateral movement on experimental plots of heavy metal concentrations (i.e. since 1942) which he cautiously attributed to cultivation practices although other factors such as soil density changes as a result of adding organic matter (a *dilution effect?*) may have played a part. McGrath dismissed losses due to crop removal and leaching as negligible.

3.3 LABORATORY ANALYSIS

The laboratory analyses adopted in this study were all well-tested standard techniques. The following descriptions are therefore fairly brief and more detail can be found elsewhere (e.g. see Jackson, 1958; Ball, 1964; Aston, Martin & Jackson, 1998a etc).

Soil Preparation: The soil samples were taken to the laboratory where they were passed through a 2 mm mesh stainless steel sieve; if samples were unduly wet, partial air drying was carried out before sieving. Plant debris and stones were removed from the sample during the sieving process. Each sieved sample was homogenised in the collecting tray and placed in a paper bag and allowed to dry at ambient temperatures. After pH and magnetic susceptibility measurements were taken soils were further dried at 80° C in a forced draught oven.

[59] Except of course in the deliberate creation of medieval strips or of lynchets.

pH: Assessments were made in the laboratory on homogenised suspensions of air dried soil (4g from each sample) in de-ionised water (16 ml) using a conventional pH meter. A reference standard solution of pH 7 was used to calibrate and recheck the meter setting. Laboratory testing of soil pH avoided seasonal and microclimate variability that occurs in the field and enabled a more objective comparison.

Magnetic Susceptibility: Measurements were made in the laboratory on 10 ml sub-samples of air-dried soils using a Bartington Magnetic Susceptibility Meter. The apparatus is designed to generate a low intensity alternating magnetic field and record any disturbance to the oscillator frequency caused by the sample. After checking the calibration with a 1% magnetite sample, the meter was switched to a low frequency setting and the display set for S I units (volume susceptibility units or κ). The apparatus was operated on a vibration free bench and remote from potential error-inducing sources such as metal objects or electrical/magnetic fields. Samples were contained in 10 ml cylindrical plastic bottles and measurements taken to an accuracy of 1%. NB. Inter-sample comparability was more important than absolute values hence standardised operating conditions were paramount. Every tenth sample was retested as a routine and all anomalous (unusually high or low) readings retested at least three times.

Analytical Procedures: Accurately weighed sub-samples (approx. 1.0000g) of each soil were placed in 100ml wide-necked Ehrlenmeyer flasks. These flasks had been previously cleaned in decontaminating fluid (Decon-90) and repeatedly rinsed with deionised water before oven drying. 10ml of Analar concentrated (specific gravity 1.4) nitric acid were added to each sample and the flasks placed on a hot plate in a fume-cupboard. The samples were heated to just boiling point and simmered until digestion was complete, approximately 1 hour. As soon as the digests were cool[60], they were filtered through Whatman No. 1 filter paper and made up to volume (50ml) with deionised water. A check on experimental bias was maintained using acid blanks, i.e. 10ml aliquots of acid without soil which were boiled and filtered in the same way, and using standard solutions with known concentrations of the various test metals. The filtered acid digests were sealed and stored until the AAS was available for use. Fresh samples and the same samples stored for over six months gave consistent measurements.

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[60] If filtration is delayed (over night, for example) digestion will continue and introduce an induced bias into subsequent measurements.

Chemical Analysis:

a) Metals: Soil digests from each of the investigate sites were analysed for cadmium, chromium, cobalt, copper, lead, manganese, nickel and zinc content using an atomic absorption spectrophotometer set up according to manufacturers instructions (see comments on spectroscopy below). Background correction was used where appropriate and the precision of the machine set to between 0.3 and 0.5%. Concentrations of each element in the soil were calculated in mg/kg dry weight of soil. Digests tested for the more soil-abundant elements such as zinc and manganese required dilution before testing and the ensuing results adjusted accordingly. The relatively soil-scarce element cadmium did approach the limits of the spectrometer's sensitivity but nonetheless produced acceptable results. As with any piece of scientific measuring equipment the AAS was subject to calibration and re-calibration. To counter any "drift" in the spectrometer's accuracy it was reset after every ten assessments (more often than recommended by the manufacturer). An acid blank and then a standard solution followed each group of ten. After long runs (8 hours or more) when the machine was very hot some drifting would occur. Data from the standard solutions enabled any necessary correction to the affected readings.

b) Phosphorus: Using the nitric acid digests, aliquots were analysed for phosphate using a vanado-molybdate solution and the resulting colour read at 460nm on a spectrophotometer following standard procedures (Jackson, 1958). The "molybdenum blue" method (see Box 2.3 on page 95) was inappropriate because of the oxidising properties of nitric acid. The coloration of the digest (pale straw yellow) is usually insufficient to mask the more intense yellow created by the indicator although this can be a problem with digests from very organic soils (or of plant material). The spectrophotometer was zeroed using deionised water and reagent blanks, and corrections were made when required for any phosphate present in the acid (digest blanks) and for opportunistic nitric acid oxidation products (digest without reagents). As with the AAS, the spectrophotometer was calibrated before each batch. In this case batches of several hundred aliquots were dealt with in a run. Drift was never demonstrated to be a problem.

***c) Loss on ignition*:** Oven-dried test soils were re-dried at 105°C and sub-samples of approximately 1.0000 g soil were placed into small crucibles and ignited in a muffle furnace set at 450°C for a period of 6 hours. The samples were re-weighed and the

percentage weight loss (of organic-carbon based material) calculated. The process is based on established procedures that measure organic carbon with reasonable accuracy, i.e. without disturbing the mineral components (carbonates) or inducing loss of structural water in the clay fraction (Ball, 1964). The technique only evaluates organic carbon as a total figure and cannot offer any distinction between elemental carbon (as charcoal fragments), biota (plant and animal material), cellulose, hemi-celluloses, lignin, lipids or the more complex humic substances. Nevertheless, such analyses are easy and quick to perform and results could be turned around in couple of days making it a useful option for the archaeologist.

Spectroscopy:

Mass spectroscopy is a technique whereby the mass and relative abundance of elemental ions within a test material can be measured. The means of doing this have become increasingly more sophisticated in recent years (see below). In atomic absorption spectroscopy (AAS), a long established methodology; a digest of the test material is vaporised in a flame. Measurements of the degree to which light at the resonant wavelength of any particular element is absorbed by ground state atoms enables the calculation of the concentration of that element in the solution. The concentrations of cadmium, cobalt, copper, chromium, lead, manganese, nickel and zinc in prepared digests were evaluated by AAS following standard procedures (see Jackson, 1958; Bassett *et al*, 1978; Ure, 1995). Concentrations of metals were calculated in μg per mg (which equates to parts per million or mg per kg) from each soil (1g) digest reading the AAS readouts to a precision of 0.001. Detection limits on a sample basis were ± 0.05 ppm. Because of nature of the internal programming of the AAS it is possible to set the statistical parameters of each sample-element analysis, viz: the machine takes repeated measurements at operator controlled intervals (e.g. 3 seconds) until the variability in readings is reduced to a predetermined value … usually set at 0.01%. In this study a standard digest was prepared and used every ten sample digests throughout all the analyses so that any drift or variation in spectroscopic readings could be corrected. Batches of digests were also subjected to repeat evaluations. As a result, assessments proved to be precise and repeatable.

Several contemporary workers (Entwistle, 1994; Linderholm & Lundberg, 1994; Rimmington, 1999) have used more advanced spectroscopic techniques, in particular inductively coupled plasma atom emission spectroscopy (ICP-AES) which, by generating much higher temperatures, can measure the spectrum values of light emitted

from the excited atoms of a range of elements simultaneously. The advantages of a multi-element analysis are manifest, but the more sophisticated technique did not come without its complications (see Part 6).

3.4 DATA PRESENTATION

3.4.1 Isoline Maps:

The main method chosen to present data in this study is as isoline maps and the reasons for this choice are twofold. First, that the nature of the archaeological record being prospected (i.e. residues of human activity over a long period of time) is not discretely defined but, like the topography of a landscape, moves either gradually or rapidly (occasionally abruptly) between measured values. The individual samples are no more than points of data (analogous with spot heights on a contour map) separated by inferred information only. Note, however, the "spot heights" in the soil surveys are confined to grid intersections. The highest recorded value is not necessarily the precise focus of activity. Secondly, isoline presentation allows a certain amount of data manipulation that can facilitate interpretation. There is a choice at which interval to set the isolines. To maintain both consistency and objectivity the choice has been to set intervals close to integer or half integer standard deviations[61]. Even so, and as part of the inevitably subjective process of interpretation, increasing or decreasing isoline values can often bring into focus patterns of interest or show that what seems to be interesting is less than it appears. To return to the first point, something needs to be said about heterogeneity and, what may appear to be, anomalous readings. In a landscape of past human activities there will be a palimpsest of soil enrichment. The analysis of a single trowelful of soil is unlikely to tell us a great deal. Samples from a wide grid will tell us more but will miss much. Samples from a very fine grid over the whole landscape (were such an exercise even practicable) will provide a plethora of information but clarity will require some filtering out of "noise". There is obviously a happy medium where what data are lost is balanced by the clarity of what remains. In the field scale prospections undertaken for this thesis a sampling grid of ten to twenty metres proved both manageable in the field and laboratory, and provided consistent results. Sampling in an intensively settled multi-period site in "Church Field", Shapwick, for example, on a 15m and then on a 5m grid demonstrated that the greater the intensity of the sampling the wider the range of concentrations recorded, including

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[61] Generally +0.5 sd, +1.0 sd and +2.0 sd ... although negative standard deviations are used to illustrate particularly low values

the occasional very high value or "spike". Although undoubtedly real, localised rich remnants, especially if they are single samples, need to be treated with caution. If, by chance, they are picked up in less intensive surveys these "spikes" can be confusing to the interpretation. They may well represent a patch of past activity too small for the sampling net to catch or they could be evidence of something less ancient and more fortuitous, for example, modern incidents such as a tractor fire, spilled diesel, the siting of a galvanised water trough, etc, all of which can provide localised and quite intense concentrations of soil elements which time has not yet diluted or dispersed.

3.4.2. "Anthropogenic" and "Non-Anthropogenic" Soils:

Data from my own investigations prior to starting this piece of research together with results from several undergraduate projects at Shapwick (see Appendix II on the accompanying CD) indicated that certain soil factors were associated with ancient settlement sites. These factors, not always consistent in their behaviour, have been hypothetically categorised as "anthropogenic" and "non-anthropogenic". Isoline maps of "anthropogenic" and "non-anthropogenic" soil factors are presented in Part 5, together with the actual statistical associations or "clusters" associated with any particular site. The hypothesis that there are, by and large, grouped soil-indicators of past human activity is also discussed in Part 5.

3.5 DATA ANALYSIS

As has been stated in the introduction to this thesis the primary object of the research has been to develop the practical aspects of archaeological soil analysis and prospection. The accumulation of a large data base has afforded the opportunity to provide objective evaluations of the findings and to test their meaningfulness. The statistical analysis presented here is by no means exhaustive.

For most of the sites investigated soil sample measurements have been recorded for the heavy metals lead, copper, zinc, cadmium, nickel, cobalt, chromium and manganese; of phosphorus and organic carbon (loss on ignition); of soil acidity and magnetic susceptibility. These data are presented as soil concentration isoline maps and degree of co-incidence with the known archaeology is, in many cases, clearly apparent. However,

as not all these associations are positive and some not clear at all, it is necessary to look more objectively at the data.

This section considers sample variability, correlations between soil factors, the application of cluster analysis and the principles of isoline mapping.

3.5.1. Variability:

a) Within and between sample variation:

An assessment of the variability within individual soil samples compared with that found between samples was made by two Biological Sciences undergraduates at the University of Bristol in 1996 and their results have been adopted in this report.

Bartley and Farmer analysed soils from the western end of Sladwick Field, Shapwick[62] following precisely the same procedures and conducted in the same laboratory as used by this author. These researchers took seven measured ($\approx$ 1 g) sub-samples from each of four randomly chosen soil samples and, using the extraction procedures described above (see page 119), assessed each for concentrations of phosphorus and seven heavy metals[63]. They found that the variability within the sample (i.e. between sub-samples) was significantly less than between samples ($p \leq 0.01$). On the basis of these calculations and for the purposes of this thesis, within-sample variability was discounted as significant contributor to experimental error.

b) Sample variation with depth:

Bartley and Farmer also analysed soils from the top 15 cm (after removal of the turf layer) and from 15 – 30 cm. Twenty four paired upper and lower samples were processed and the concentrations of phosphorus and seven heavy metals evaluated. There was no significant difference in the concentration of the measured elements between upper and lower samples. On this basis (supported by the evidence of previous and successful top-soil surveys), it was decided to sample all soils within this top 15 cm.

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[62] These original soil samples were incorporated into the whole field survey undertaken in this report and accordingly re-analysed.

[63] Assessments were for lead, copper, zinc, cadmium, nickel, chromium and manganese.

3.5.2. Correlation of soil element concentrations with other data:

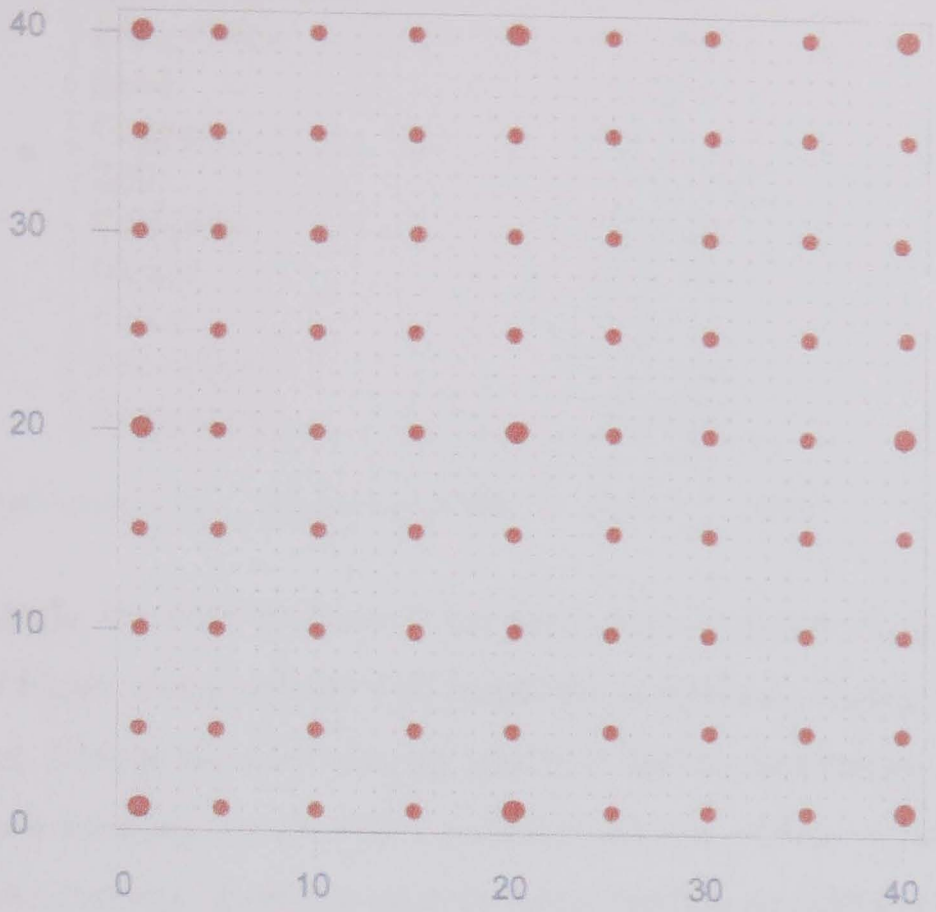
The degree to which the various soil factors (within each site) were independent of each other or correlated in some way was calculated from paired values. Correlation coefficients (Pearson) were produced (see data for each site in Appendices I and II).

It is tempting to try to correlate soil element concentrations with other types of survey data such as geophysical measurements and artefact counts from field walking. Such data are seldom equable and such correlations should be treated with circumspection.

In this thesis, geophysical assessments (magnetic susceptibility) have been made both on the collected soil samples in the laboratory. However, the collection of most geophysical data in the field is done at intervals seldom exceeding one metre, the numerous data points providing the pixels for graphic display. Over an area of, for example, 40 metres square a resistivity survey will easily log 1600 separate pieces of information. A soil survey on a fairly standard 20m grid interval will provide four data points. Even intense sampling at 5m grid intervals will provide only eighty one data points (see Figure 3.1). It can be argued that attempts to average out aggregates of 400 or even 20 geophysical readings would make nonsense of the data. It is unlikely to be profitable to treat information from dispersed soil sampling points as pixels. This should not be surprising as there is a fundamental difference between the two approaches. Geophysical surveys search primarily for buried archaeology, e.g. ditches, pits, walls, hearths or disturbed ground, which often can be graphically displayed as linear features or delimited areas[64]. Geochemical surveys are more attuned to identifying areas of activity which may well have no precise association with an excavatable feature. Whereas the former improve in definition with increasing data points, the latter, in being a measure of a more amorphous record, may well become confusing if the focus is too intense.

[64] This is a generalisation, of course. Magnetic susceptibility measurements are clearly useful in establishing areas of heat related activities, which is why this technique was included in this thesis.

Figure 3.1 Geophysical and Geo-chemical Surveying
– geophysics survey points (grey) and geo-chemical sample points (red)in a 40 m quadrat.



Geophysical survey with 1600 pixells : Geochemistry 5m grid with 81 sampling points: Geochemistry 20m grid with 9 sampling points

Bartley and Farmer, nevertheless, attempted to investigate possible correlations between soils samples (20 metre grid – 24 samples) from an area at the eastern end of Sladwick Field in Shapwick (60m by 100m) and a resistivity survey (Andrews *et al*, 1997)[65] over the same area (6000 pixels). The actual resistivity readings were not used but the dots (pixels with resistance values above an unstated threshold) on a dot-distribution map 'surrounding' each soil sampling point were counted and scores allotted. When these scores were compared statistically with soil concentrations of the elements tested the results were inconclusive.

The technique was re-examined using actual resistivity data. An area of 0.72 ha (eighteen 20m x 20m grids) in Church Field, Puxton had been surveyed for resistivity by students from the University of Exeter. Mean resistivity values (of each grid total of 400 readings) taken from this survey were compared with the soil analysis results from single samples taken from the centre of each grid (see Appendix II). The correlation coefficients (Pearson) are summarised in Table 3.3.

[65] A subsequent unpublished magnetometry survey was also carried out by Geophysical Surveys of Bradford.

Table 3.3 Correlation of soil readings with resistivity data (Puxton)

Soil evaluation	Correlation
Magnetic Susceptibility	0.303
Loss on Ignition	0.008
Phosphorus	0.065
Lead	0.444
Copper	-0.027
Zinc	-0.073
Cadmium	0.163
Nickel	**-0.524**
Cobalt	0.234
Chromium	-0.340
Manganese	0.122

(Degrees of freedom 16 $*p \leq 0.05 = 0.468$ $**p \leq 0.01 = 0.590$ $***p \leq 0.001 = 0.708$)

Interestingly, the analysis showed that there was a significant negative correlation ($p \leq 0.05$) of higher soil resistivity with nickel and a moderate degree of correlation ($p \leq 0.1$) with lead. Despite the discouraging results of Bartley and Farmer, it is suggested that where soil sampling can provide a sufficient amount of data within an area of geophysical survey, statistical analysis might provide an objective evaluation of the association of anthropogenic deposits and archaeological features.

Most of the sites investigated in this study were wholly or largely under permanent grassland or were wooded. The association of anthropogenic soil residues with previous settlements has depended on surface evidence (earthworks, pottery scatters) or features revealed by geophysics or excavation[66]. In this thesis, what field walking data there is, was fortuitous, often gleaned from previous studies (e.g. at Shapwick) or from concurrent investigations undertaken by other workers (e.g. at Puxton). The latter were prescribed by conventional protocols and carried out subsequent to the soil sampling, that is to say, the collection of field walking data was not built into the research design of this thesis.

Field walking data are most often collected along linear transects separated by distances comparable to the spacing of a soil sampling grid. With conventional field walking, the best that can be hoped for is a transect centred on the point where the soil sample has been removed. In practice, even when working together, the ever economical archaeologist invariably confounds the soil sampler by adopting the canes marking a soil sampling locus as the starting or finishing point of each traverse. Attempting to

match the soil analysis with the artefact count measured by taking average values between two soil samples or even reading appropriate measurements from an isoline plot involves using the same value twice (for contiguous transects). This, unfortunately, compromises the integrity of any statistical analysis.

Distribution maps of sherd density for Shapwick and Puxton are presented in the Part 4 (see pages 138 & 159) but attempts at an objective evaluation using statistical correlations were abandoned. It is suggested that for future research a procedure of field walking designed to encompass a defined area around the soil sampling point(s) might provide useful objective evidence for association of artefacts and anthropogenic soil residues.

3.5.3. Cluster Analysis:

Cluster analysis is a standard multivariate statistical procedure where similarities in the measured data are arranged in hierarchical dendrograms, that is, factors are grouped according to how alike they are (see Everitt, 1980). Its application to archaeology has some provenance. It has been used in the USA to interpret soil analysis results from Native American hut floors (Middleton *et al*, 1996). Cluster analysis was chosen for two reasons. First to provide some objective evidence for the observed geographical associations of soil factors demonstrated by the isoline maps. In the event, this was only partially successful (see Part 5, page 220). Secondly to provide objective evidence of multiple soil factor signature of past activities. Again this met with only tentative success (see Part 5, page 233). The use of cluster analysis, although not inappropriate for this thesis, needs to be treated with some caution (see Everitt, 1980, p59). For example, the sequential linkage of factors at a fairly low level of similarity can, rather than demonstrate any real "clustering" as such, just be a representation of what the method does (see as an example Figure 5.13 C). Attempting to interpret the archaeology on the basis of such a dendrogram, in terms of factor aggregation at least, would be meaningless.

The cluster analysis of the data presented in this thesis was performed using ***Minitab 12*** software package. The programme option adopted identified each cluster of variables thereby classifying them into groups. One reason to cluster variables is, of course to

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[66] In fact the discovery of the Roman settlement in Lower Woods, Gloucestershire was prompted by pottery finds within adjacent wood banks. There were no earthworks and the geophysical survey was used to confirm what soil analysis had already revealed.

reduce their number and to perhaps allow the recognition of site related soil changes. The adopted method (i.e. a variables matrix with a single linkage[67] between factors) is able to produce clusters that are more intuitively understood than those found using other methods (see Minitab Reference Manual, 1995).

The procedure is an agglomerative hierarchical method that begins with all variables separate, i.e. each forming its own cluster. In the first step, the two variables closest together are joined. In the next step, either a third variable joins the first two, or two other variables join together into a different cluster. This process continues until all clusters are joined into one. The final grouping of clusters, also called the "final partition", is that which will, hopefully, identify groups whose members share common characteristics. The completed dendrogram is a graphical depiction of the amalgamation of observations into one eventual cluster.

Time has not allowed an exhaustive statistical analysis of the data. It is recognised that other statistical procedures (e.g. spatial analytical techniques) might produce more information and allow further interpretation of the results. Be that as it may, the primary aim of the thesis was to test the potential use of the methodology described above.

3.5.4. Isoline Mapping:

Some general points about isoline mapping have been made already (see page 123) but some detail is required on the specific procedure adopted for this thesis. The isoline maps were all generated using ***Minitab 12*** software package. This software uses the term "contour plot" which has, in this dissertation been replaced by the more accurate description "isoline map". Such maps are a two-dimensional graph of three measurement variables: x, y, and z. The z-variable (a soil factor measurement) can be regarded as extending in/out of the graph plane. The "contour" or "iso" lines represent the magnitude of the z-variable. In the map, isolines are, by definition, made up of equal z-values in the x-y plane. The programme bases the interpolation of the isoline after evaluating 15 data points along the x-axis and along the y-axis. The extent of interpolation can be altered and, where this has been done (isoline maps annotated as "interpolated") a figure of 50 data points in each direction was chosen (see for example Figure 5.5 C).

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[67] Single linkage clustering is considered as the most mathematically sound by critics of the method - see Everitt, 1980, p 69)

Part Four: Site Descriptions

INTRODUCTION

Eleven sites were investigated. An earlier and less detailed survey of one of these sites together with a twelfth site, both of which were initially included as part of the masters degree which preceded this study, have also been included. Their inclusion is justified in that, following new research reported below, the original data have become open to re-analysis. The sites are, for convenience, divided into four groups. Group A (Sites 1-3) investigates changes in settlement patterns on the wetland edge of southern Somerset and are tied in with the Shapwick Project (King Alfred College, Winchester and the University of Bristol). Group B (Sites 4-7) investigates Roman rural settlement and Medieval resettlement in the alluvial lowlands of north western Somerset and were carried out in support of work initiated at the University of Exeter. Group C (Sites 8-9) investigates woodland and woodland edge sites in Gwent and South Gloucestershire (Roman and post-Roman), and Group D (Sites 10-12) are surveys of two medieval religious settlements, one in Galway in the Republic of Ireland and the other in North Yorkshire.

Table 4.1 Site Location and Type

Location				Type of Site	Group
Site	County	Village	Field		
1a*	Somerset	Shapwick	Church Field 1996	Roman - Medieval	A
1b			Church Field 1998	Roman - Medieval	
2			Henry	Early Medieval	
3			Sladwick	Roman	
4		Kenn	Hamm Farm**	Roman	B
5*		Puxton	Church Field	Roman - Medieval	
6		Huntspill	Vole Farm	Medieval	
7			Hardingworth	Medieval	
8	Gloucestershire	Hawkesbury	Lower Woods	Roman	C
9	Gwent	Tintern	Blackcliff Woods	Early Medieval	
10	North Yorkshire	Kirkdale	Kirkdale Church S	Medieval	D
11			Kirkdale Church N	Medieval	
12	Galway	Abbey	Kinaleghin Priory	Medieval	

*initially part of MA thesis. ** Please Note: Hamm Farm is often referred to as Kenn Moor in figures.

Please Note: Unless annotated otherwise all the following maps and plans (not photographs) are oriented with north towards the top of the page.

The first three sites are fields within the Somerset parish of Shapwick (see Figure 4.1) and were investigated as part of the Shapwick Project (Aston, 1989; Aston, 1990; Aston & Costen, 1992; Aston & Costen, 1993; ; Aston & Costen, 1994; Aston & Gerrard, 1995; Gerrard & Aston, 1997; Aston *et al*, 1998d).

Figure 4.1 Southern half of Shapwick Parish, Somerset (after Gerrard & Aston, 1997)

The Shapwick Project

The Shapwick Project began in October 1988 as a joint exercise between King Alfred's College, Winchester and the University of Bristol. It finished in 1999. One of the prime aims of the Project was to investigate the development of the settlement pattern in the parish. The hypothesis had been that the village was at some time planned and that it replaced a more dispersed settlement pattern of scattered farmsteads and hamlets. The assumed time for this development was somewhere between the eighth and twelfth centuries AD; the evidence eventually pointing strongly to the tenth century.

This hypothesis was based on growing body of evidence from across England (and indeed Europe), which indicates that villages are a relatively late development and that they replace an older, widespread and more persistent pattern of hamlets and of farmsteads (Taylor 1983) ; this 'older' distribution still surviving in the dispersed

patterns seen particularly in the western parts of Britain. It is argued (Roberts 1987) that the general model for the development of post-Roman settlement in some parts of England was one of a gradual but dramatic replacement of a previous, i.e. late Roman, dispersed pattern of hamlets and farmsteads by a smaller number of nucleated village settlements which in many cases were planted and planned. It is further suggested that this process was associated with the development of common field systems - indeed, the creation of these field systems may have been the impetus for nucleation (Fox 1981).

In England, this model was developed from the growing body of evidence from archaeological research, particularly in the eastern parts of the country and work on deserted villages elsewhere. In the East Midlands and East Anglia, extensive fieldwork by, for example, Wade-Martins (1980) and others located pottery scatters indicating pre-Conquest settlements in ploughed land outside the areas of villages, suggesting that the settlement pattern had changed and that, in many cases, pre-Conquest settlements had been replaced by medieval villages.

However, similar work in the west of England is somewhat hampered by the predominance of (often long term) grassland, smaller fields with hedgerows, and a greater proliferation of woodlands (Rackham 1986), all of which impede fieldwalking.

Also, whereas in the east of England there is a continuously developing pottery industry from the post-Roman period through to the middle ages, with recognisably different types and sources over the centuries; in the western parts of the country, the situation is rather different. For much of the period 400 to 900 (or even 1100) AD there seems to be very little, if any, pottery in use - the period is 'aceramic'.

Pottery does not reappear in many parts of the west until the tenth century. In Somerset, for example, the pottery series at Cheddar begins by the tenth century i.e. it could be ninth century (Rahtz 1979) , whereas in Wales there is little before c 1100 AD (Edwards and Lane 1988) . There is, therefore, no ceramic evidence for settlement sites over much of the west of the country from the fifth to at least the tenth century. Consequently, over wide areas of the country there is little chance of recognising low-status settlement sites from archaeological evidence, although there is some evidence for Cornwall (Thomas 1968; Hutchinson 1979) . If the ordinary agricultural settlements of this period are to be located and characterised, assuming they existed, the archaeological evidence needs to be teased out by the application of a variety of approaches.

At Shapwick, notwithstanding the difficulties peculiar to the west country, *fieldwalking* over ploughed land as it became available was employed extensively. On long-term grassland finds were collected by *shovel-pitting*. The use of *documentary and cartographic evidence* proved to be very important. Other investigative approaches at Shapwick included *analysis of the village plan, building surveys, excavations*, and one-metre square *test pits* in village gardens.

The problem of identifying *aceramic* sites is also compounded by other aspects of post-Roman and Anglo-Saxon settlements. Construction was usually in wood and perhaps, in some cases, not using post holes or sunken-floored features; buildings based on sill beams on the ground surface would leave little trace after subsequent ploughing. Apart from a lack of pottery, this period is generally distinguished by its lack of inorganic finds, whether it be metal (iron, bronze), glass or burnt clay. From fieldwork one would not know whether any ironwork or burnt daub fragments were necessarily from this period (although at Cowdery's Down the *only* surface indications were lumps of burnt daub: Millett & James 1983).

Another approach to the recognition of settlements which have no surface indications of diagnostic pottery or other inorganic objects and which, if excavated, would have little in the way of structures, let alone stratification, and perhaps still fewer finds might be to look for *changes in the soil* which could have been caused by human occupation. These otherwise invisible soil anomalies can be recognised only by *geo-physical* and *geo-chemical surveying*, and sometimes only by the latter.

In 1996 a geo-chemical survey was made of a fairly well researched site ("Church Field") in the parish to see if the confirmatory or new information could be recovered. This was followed by a more detailed study of part of the same field in 1998. Studies were also made in 1998 of two further sites, a field called "Sladwick" and a group of fields referred to collectively as "Henry".

The Soils of Shapwick

The parish of Shapwick lies on the northern (dip) slope of the Polden Hills in central Somerset. The higher land to the south of the parish lies on the Lower Lias which is constituted of thin limestone bands inter-bedded with clay shales and marls. As the solid geology dips northward grey calcareous clays become more common until it is obscured

by later superficial deposits, mainly of peat. However, the most prominent and oldest deposits are the low east-west ridges of calcareous sands and gravels known as *Burtles.* The Burtle Beds were laid down as beaches or offshore sand banks during periods of high sea level during the Pleistocene (i.e. during one of the several interglacials approximately 100,000 years ago). During the Late Devensian (10,000 - 25,000 years ago) at the height of the last ice advance, sea level dropped by as much as 100m. This resulted in many rivers, including those flowing west across Somerset, cutting deep gorges and canyons. At the end of the Devensian glaciation sea level rose rapidly and these deep valleys were once again buried in alluvium. These deposits approach a thickness of 20m in the north of Shapwick parish. The succession within these deposits starts with a basal peat (remnants of pre-transgression forest) followed by interchanging bands of marine clay, silts and clay-peats (salt marsh deposits). At about 5,500 years ago the alluvial deposits were colonised by forests of oak and pine which in increasingly acid conditions degenerated into peat mires. Subsequent marine encroachment never reached as far inland as Shapwick so these raised bogs persist to this day and although exploited over a long period, have accumulated to depths of 5m or more.

SITE ONE

Shapwick "Church Field"

SITE DETAILS: "Church Field" comprises 7 ha of calcareous silty clay loam (Somerton Series) overlying thin beds of Lower Lias limestone and clay shales. The field lies between 37m and 25m above mean sea level sloping gently from the south west to the spring line set in a more undulating north east corner. The fairly shallow (<30 cm) soils are free draining and under an arable/grass rotation. The pH of the field ranges between 6.6 and 7.8 being on average slightly alkaline. The present village of Shapwick lies some 700m to the west and Bereway Farm a 100m to the east (see Figure 4.1).

ARCHAEOLOGICAL BACKGROUND: Church Field has been subject to various archaeological investigations since 1989 when the Shapwick Project began. Evidence for the old church itself is clear from aerial photographs (Plate 4.1) and lies to the north east of the field. What is now known of the early medieval (Saxon) ecclesiastical and administrative structure of the area would imply a church existed at Shapwick (most probably on this site) as early as the eighth century (Aston & Gerrard, 1995, 91). In 1331 the new church within the nucleated village of Shapwick was consecrated and it is

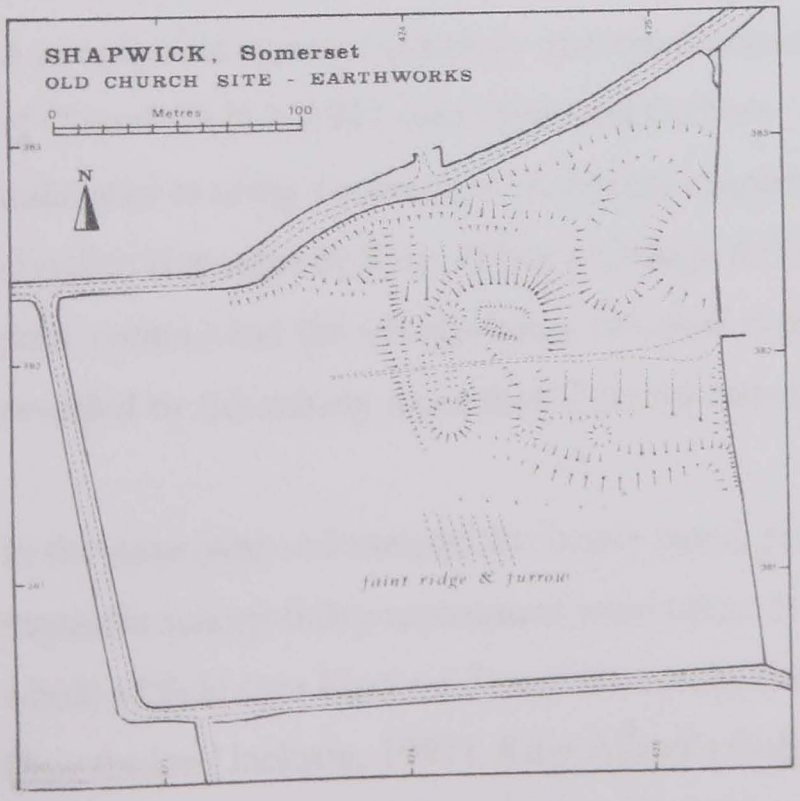
assumed that the old church ceased to function at that time and was either demolished or allowed to decay. Cropmark and parchmark on aerial photographs also suggested that settlement structures might also lie just to the south or south east of the church.

Plate 4.1 **Church Field, Shapwick**

Photo: M. A. Aston

The field has had successive earthwork surveys since 1989 and the present distribution of surface features is shown in Figure 4.2.

Figure 4.2 Earthwork survey of Church Field, Shapwick (Aston & Costen 1994)



Survey by J. Bond

The old church site is clearly visible on a mound with a possible churchyard boundary to the west and south. Some faint *ridge and furrow* was also recorded. A spring (with ceremonial associations?) is located in the north east corner of the field.

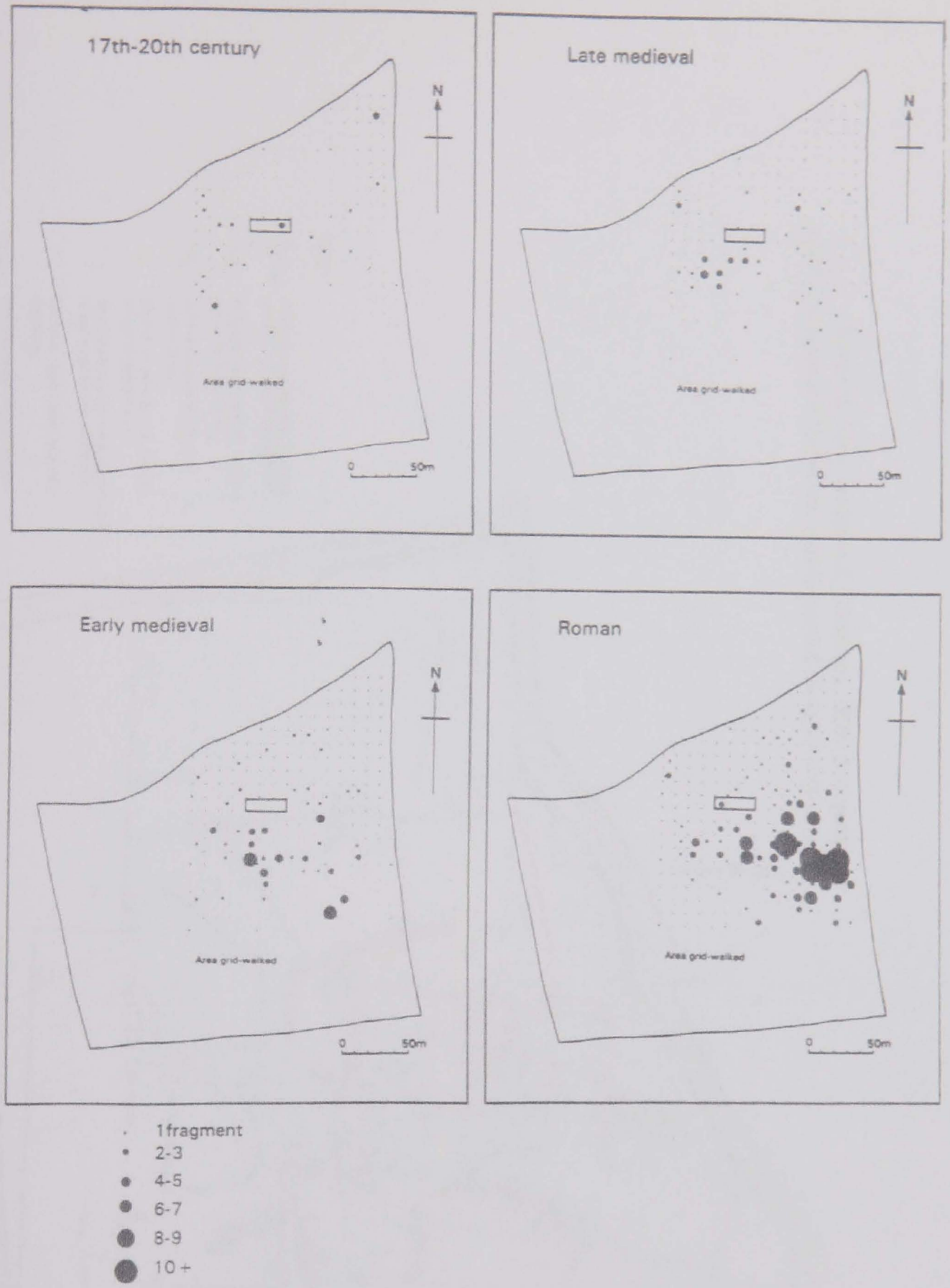
In 1993 a series of small excavations were undertaken in Church Field, which was then under grass. They provided no evidence of pre-historic but uncovered the remains of extensive third or fourth century Roman residential structures to the south east of the church. No evidence of subsequent Saxon settlement was recorded. This may have been because of the limited nature of the excavations coupled with the probability that this period was largely aceramic and used surface constructed timber buildings. It might also have meant that any local Saxon activity was located elsewhere (but see below). The limited excavation at the old church itself, although providing some evidence of a multiple structure showed no evidence of a pre-Conquest building. The absence of any architectural fittings (windows, column bases etc.) or building stone suggested that the church had been dismantled down to its foundation.

Almost immediately after the excavations were complete and the trenches backfilled, the field was ploughed. After the ground had settled and the ploughed surface had been allowed to weather, follow up fieldwalking took place (see Figure 4.3). Clear evidence of a Roman villa (roof tiles, hypocaust material, pottery and a brooch) were found east and south east of the church. But more interesting, Saxon pottery similar to that of the Cheddar ware series was found (more commonly) to the south of the church. (See comments on Saxon pottery above).This may well indicate Saxon settlement on this site. Further, flints (Mesolithic or Neolithic/Bronze age) were found near the spring suggesting this part of what is now Church field has a long association with the activities of man.

A geophysical survey (resistivity and magnetometry) was carried out on the eastern end of Church Field in 1991 (see Gater and Gaffney, 1993, 24), the results of which were influential in siting excavations. A further magnetometry survey was commissioned (English Heritage) by King Alfred's College in 1996 (Gerrard, Thorpe and Turner, pers. comm.) and the interpretation of which is reproduced in Figure 4.4. The detail revealed by this survey more than demonstrates the complexity of the site.

In the same year soil samples for heavy metal, phosphorus, loss on ignition and magnetic susceptibility assessment were taken from points on a 15 m grid across the whole of field (see Figure 4.5) and the results have been presented as part of an MA Dissertation (Jackson, 1997). King Alfred's College returned to Church Field finally in 1998 when they excavated three large trenches within the north east and archaeologically most active quadrant of the field.

Figure 4.3 Pottery finds in Church Field, Shapwick (Gerrard & Aston, 1997)

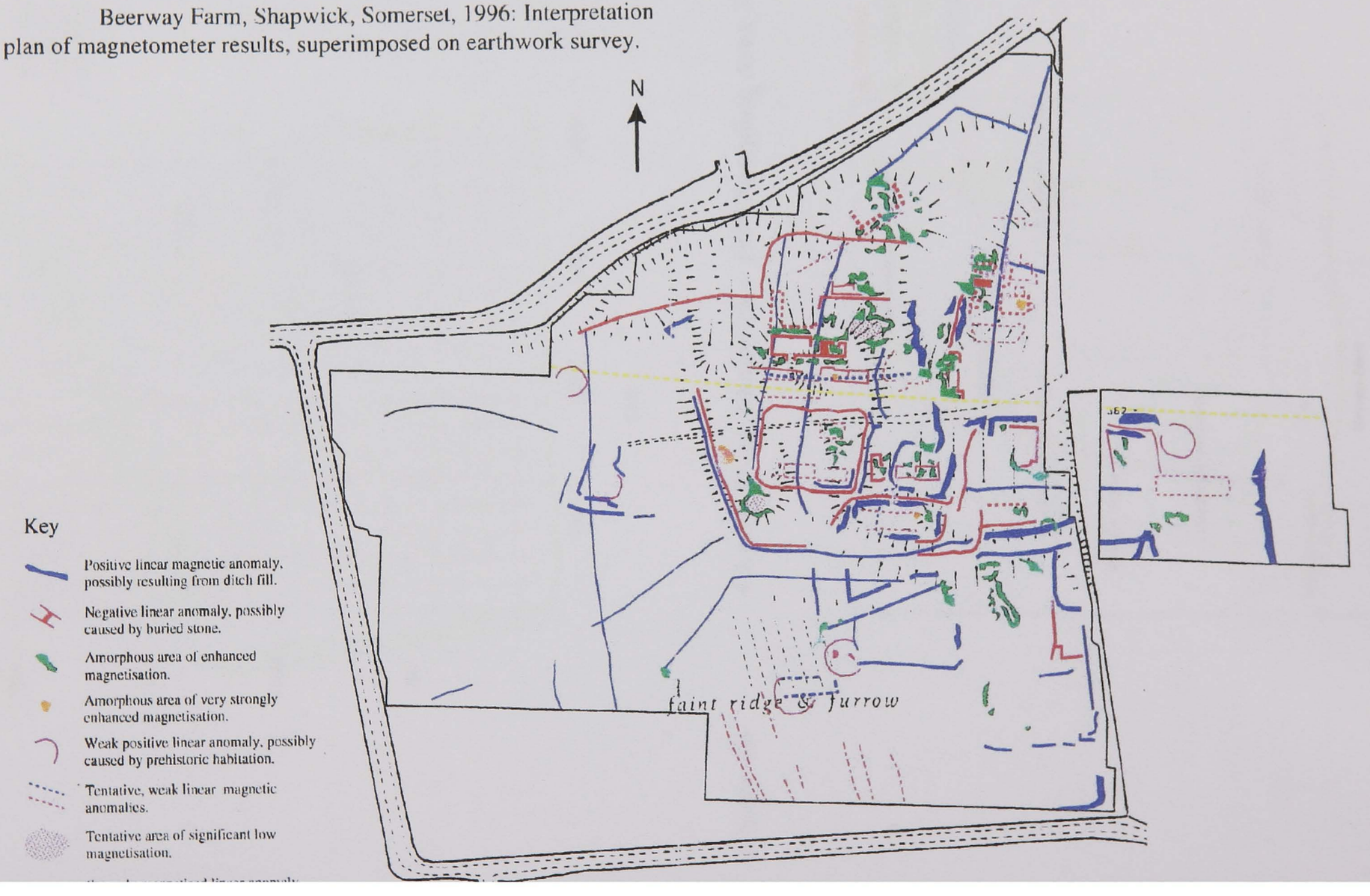


Prior to the commencement of these excavations this area of the field was re-sampled on a 5 m grid and the results of this soil analysis survey and their correlation with the known archaeology are presented in Section 4 of this thesis.

The magnetometry survey carried out by English Heritage in 1996 (Gerrard, Thorpe and Turner, pers.com.) was not available in time for the MA report. The detail revealed by this survey, more than before, demonstrated the complexity of the site.

Figure 4.4 Magnetometry Survey of Church Field, Shapwick (Gerrard, unpublished)

Beerway Farm, Shapwick, Somerset, 1996: Interpretation plan of magnetometer results, superimposed on earthwork survey.



Another and more intensive soil survey was conducted in 1998 and concentrated on a 1.8 ha zone comprising the north east quadrant of the field (see Figure 4.5 & 4.6).

Figure 4.5 **Church Field, Shapwick Sampling Grids 1996 & 1998**

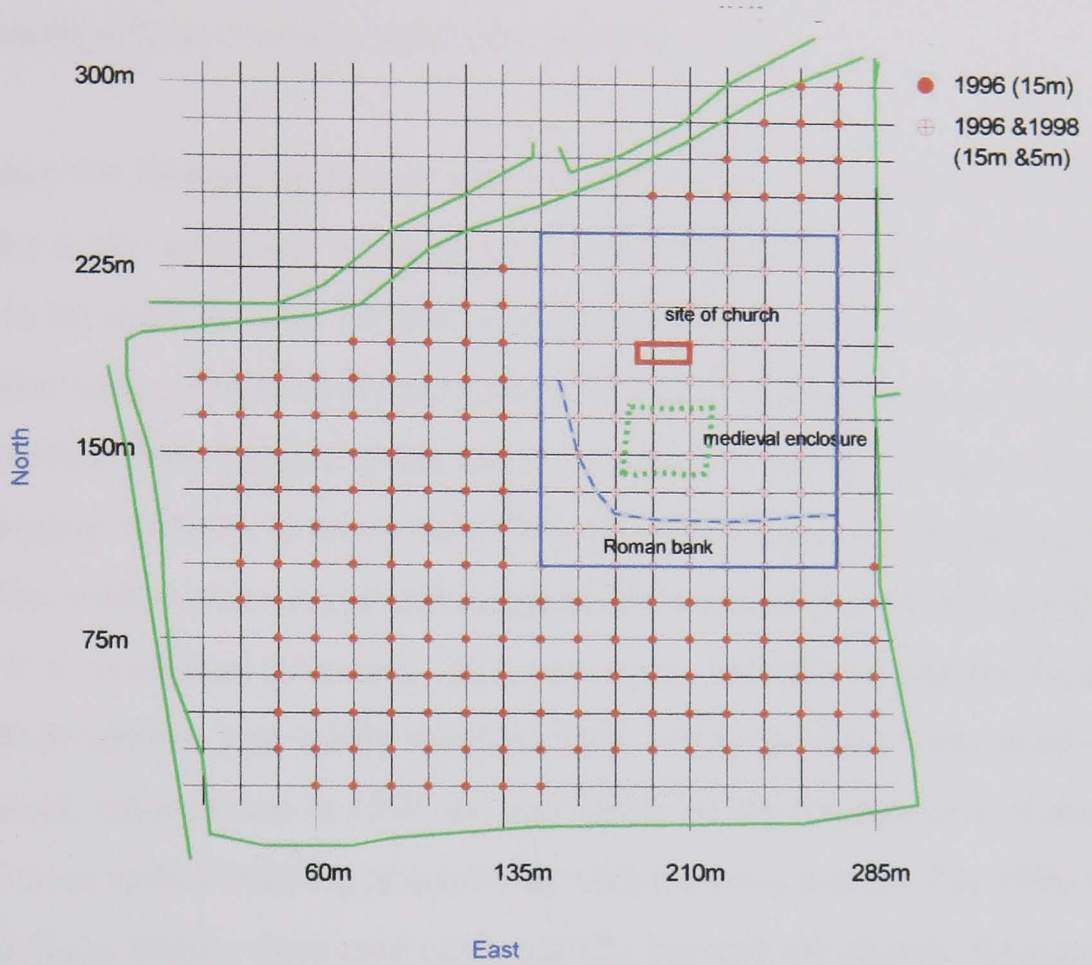
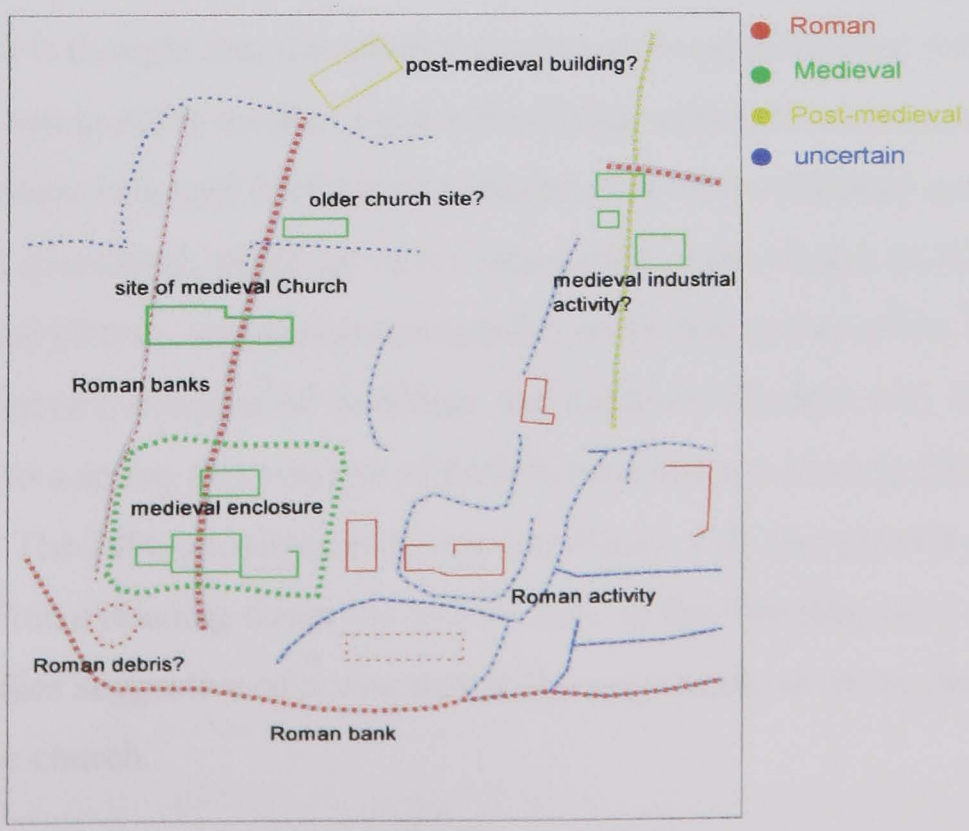


Figure 4.6 **Church Field, Shapwick – 1998 Sampling Area Archaeology**



Precisely the same sampling grid was used (15m) as in 1996 but supplemented by additional samples at five metre intervals. A total of 775 samples were taken in this area compared with 99 in 1996.

King Alfred's College returned to Church Field , after soil sampling was complete, and excavated three large trenches within the sampling area.

In summary the findings confirmed that most of the surviving evidence for Roman activity lay in the south east quadrant of the 1998 sampling zone but, because of plough damage in the shallow soils, features other than ditches were poorly defined. The geophysical survey indicated the presence of several buildings and associated ditch works. Surface finds suggested that these were Roman but there is no other archaeological evidence to prove this. The east-west ditch extending along the southern edge of the settlement area and still recognisable as an earthwork was confirmed as Roman. It is speculated (Gerrard, 2000, pers.com.) that this represents the Roman settlement boundary. Just within this boundary, where the ditch turns north-west lies a small mound. Excavations in 1993 showed this to be the remains of a (almost certainly Roman) stone walled building heaped over with masonry rubble. The 1996 geophysics indicated that a further ditch runs north passing beneath the church. Remnants of a (confirmed as Roman) east-west northern boundary were also detected.

South of the church the geophysics revealed a sub-rectangular enclosure just under a tenth of a hectare in size in which the 1998 excavation recovered the remains of a 12th century hall house. It is thought that this medieval settlement was associated with the church itself. There was possibly another medieval building within this enclosure. North of the church geophysics indicated footings of a smaller east-west orientated rectangular structure which, it is speculated, might an earlier incarnation of the church itself. To complete the medieval picture, excavation towards the north-east corner of the 1998 sampling zone uncovered a complex of buildings and evidence of a lime kiln. This complex is adjacent to a spring and vestiges of both Roman and pre-historic ditches were also identified. The 1996 geophysical survey (see Figure 4.4) also provided evidence of a long ditch extending down the eastern edge of the sampling zone which, together with anomalies suggestive of a structure at the very north, seems to post date the destruction of the church.

SITE TWO

Shapwick "Henry"

SITE DETAILS: The site investigated covers an area of approximately 4 ha which included parts of five different fields. Unfortunately the data from Field 1 was lost. These fields are situated just to the west and southwest of Manor Farm which lies half a kilometre to the west of Shapwick village (see Plate 4.2 & Figure 4.1). The soils are similar to those in Church Field on the other side of the village, being shallow calcareous silty clay loams (Somerton Series) overlying thin beds of Lower Lias limestone and clay shales. The fields are fairly level and lie between 45m and 35m above mean sea level sloping gently north. The soils are free draining and generally alkaline (pH 7.8). Two of the fields are under arable rotation and two are under long term grass.

Plate 4.2 "Henry" fields south and west of Manor Farm, Shapwick

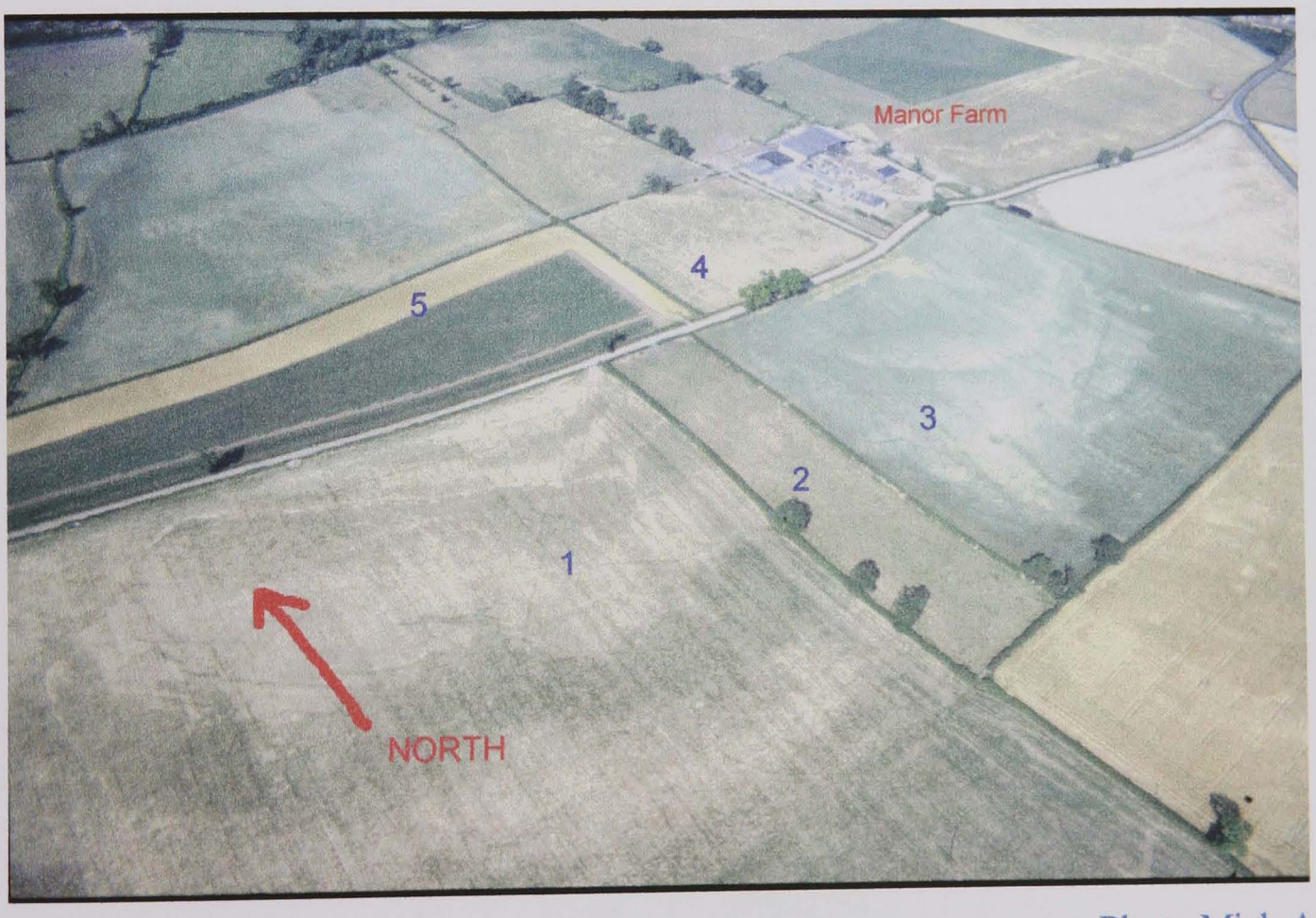


Photo Mick Aston

ARCHAEOLOGICAL BACKGROUND: The primary aim of the Shapwick Project was to discover evidence for the early medieval nucleation of settlements and the creation of the village. To meet this aim attempts were made to locate sites of dispersed pre-nucleation homesteads. A means whereby archaeologists might narrow down the location of such settlements is the use of field or furlong names; these often preserving

folk memories of previous land usage or settlement. It has been argued (Costen, 1992, 81) that, in Somerset at least, place names such as "huish" and "worth" (Old English *hiwisc* and *wyrð*) were representative of a system of agriculture that preceded the open-field system. A "worth" or "worthy" was often associated with personal-name suffix suggesting these were homesteads of some sort. In the parish of Shapwick there are several historical references to furlongs with "worth" names but only one is now identifiable. *Ennyngeworth* is mentioned in a Glastonbury Abbey document of 1327 and the furlong name survives in a group of fields west of the village each having borne over the years names derivative from *Ennyngeworth*; names that survive today as the field name "Henry" (Aston & Costen, 1993). There were no obvious earthworks in the five fields under consideration and as most were under long term pasture, field walking was only an option in some fields.

Soil samples were taken across all five fields and analysed for heavy metals, loss on ignition, phosphorus, pH and magnetic susceptibility (see Figure 4.7). Unfortunately the data for Field 1 was lost. Subsequently part of the area underwent a resistivity survey by King Alfred College (see Figure 4.8). The data from these investigations are presented in Section 5 of this report.

Figure 4.7 Henry, Shapwick Sampling Grid

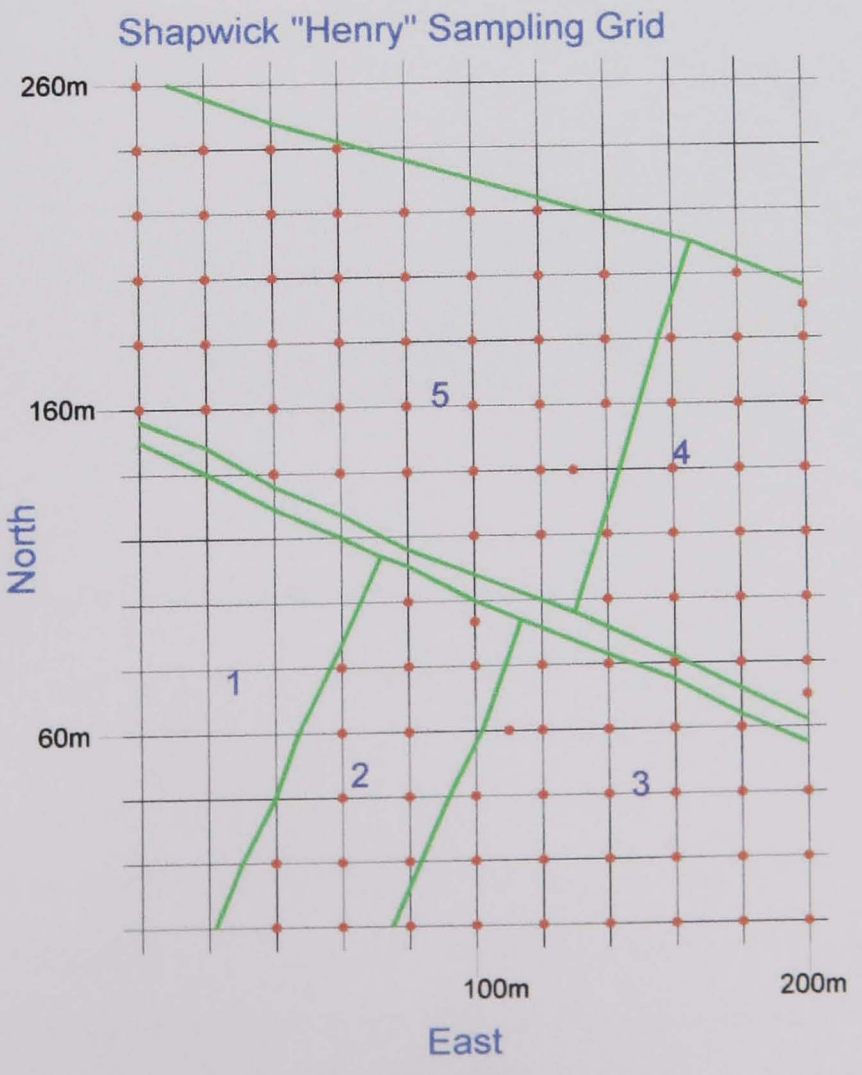
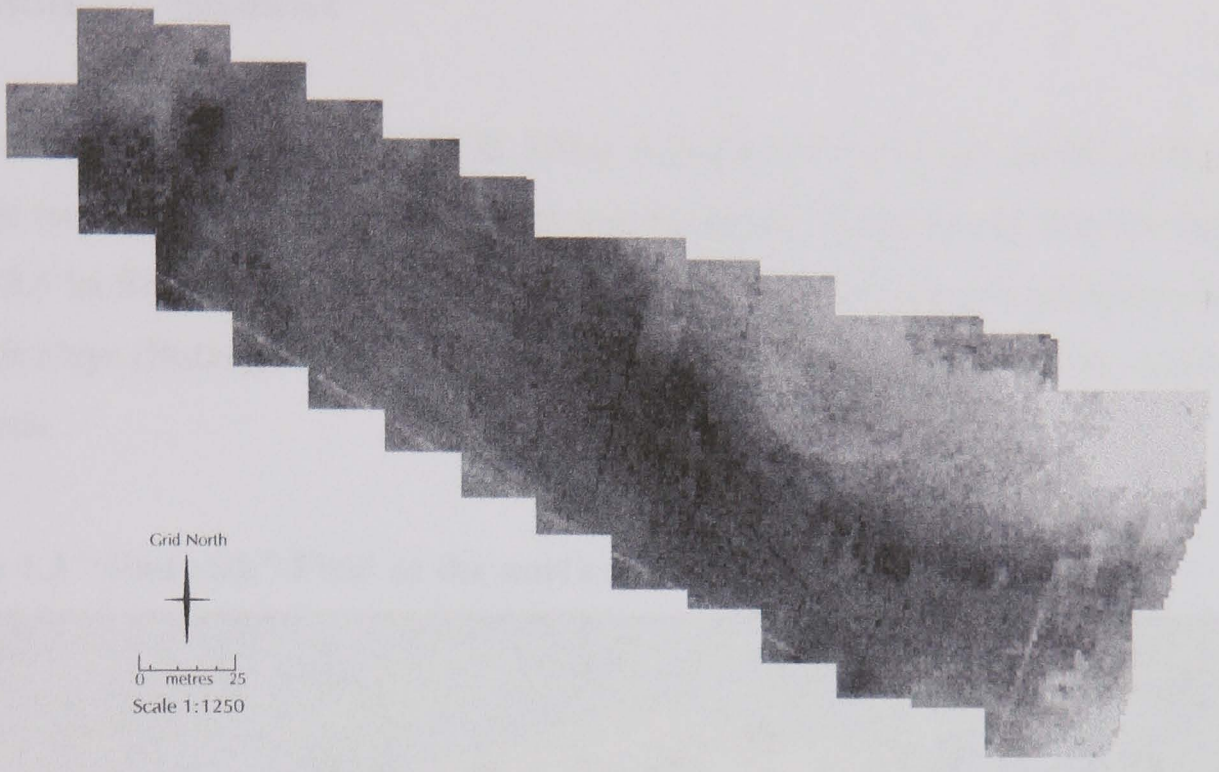


Figure 4.8 **Resistivity Survey of Henry (Field 5 only), Shapwick**

(Scale –1 sd is white, +1 sd is black) (Aston *et al*, 1998d)



Resistivity Survey of 'Henry' 1997

SITE THREE

Shapwick "Sladwick"

SITE DETAILS: "Sladwick" (Field OS 1303) is located at the lower northern edge of the village (see Figure 4.1 & Plate 4.3). Set just below the 15 m contour line, this relatively level 3.5 ha field lies on deeper and acidic (pH 5.8) alluvial soils derived from older Liassic clays (Butleigh & Fladbury Series) washed down from the northern slopes of the Poldens.

Plate 4.3 "Sladwick" Field at the northern edge of Shapwick

Photo M. A. Aston

ARCHAEOLOGICAL BACKGROUND: From the outset of the Shapwick Project it was evident from pottery sherds recovered from field walking that a Roman community had occupied parts of the present parish. It followed that these earlier settlements might well have influenced the pattern of subsequent Saxon occupation. Evidence of reversion of low lying farmland to marsh (see next section) in the post-Roman period suggested that any continuity of occupation was more likely above the wetland edge. A good half of the parish lies on the northern slopes of the Polden Hills and above the ten metre above sea level contour.

The field was recorded as early as 1303 - 1304 as "Sladwick". "Slad" (*slaed*) is Old English for marshy land and "wick" (*wic*) is another pre-nucleation suffix meaning settlement or farmstead (Costen, 1992) and is derived from the Latin *vicus* (a small non-self-governing community). It has been argued that "wicks" represent (continued?) Saxon occupation of late-Roman settlements (Costen and Gerrard, *pers. com*). Geophysical surveys (resistivity and magnetometry) in the south west corner of the field by Geophysical Surveys of Bradford in 1995 and later (resistivity) by Alex Turner of King Alfred College in 1996, revealed a prominent sub-rectangular feature (see Figures 4.9 & 4.10) suggestive of a building. This area was subjected to some localised soil sampling (Farmer, 1996 & Bartley, 1996). Heavy concentrations of lead were found to coincide precisely with the conjectured building. The site was excavated over the following two summers and a collapsed Roman building was identified (see Plate 4.4). It was decided to extend the soil survey to cover the whole field (see Figure 4.11) and the results are described later in this thesis.

Plate 4.4 Roman building in southwest corner of "Sladwick" field.

Photo M. A. Aston

Figure 4.9 Sladwick (south-west corner), Shapwick Fluxgate Gradiometry Survey.

(the presented data range is from 0.1-2.0 nT – white is low and black is high)

(Geophysical Surveys of Bradford)

Figure 4.10 Sladwick (south-west corner), Shapwick Resistance Survey

(On the plot (left) -1 sd is white, +1 sd is black (King Alfred College)

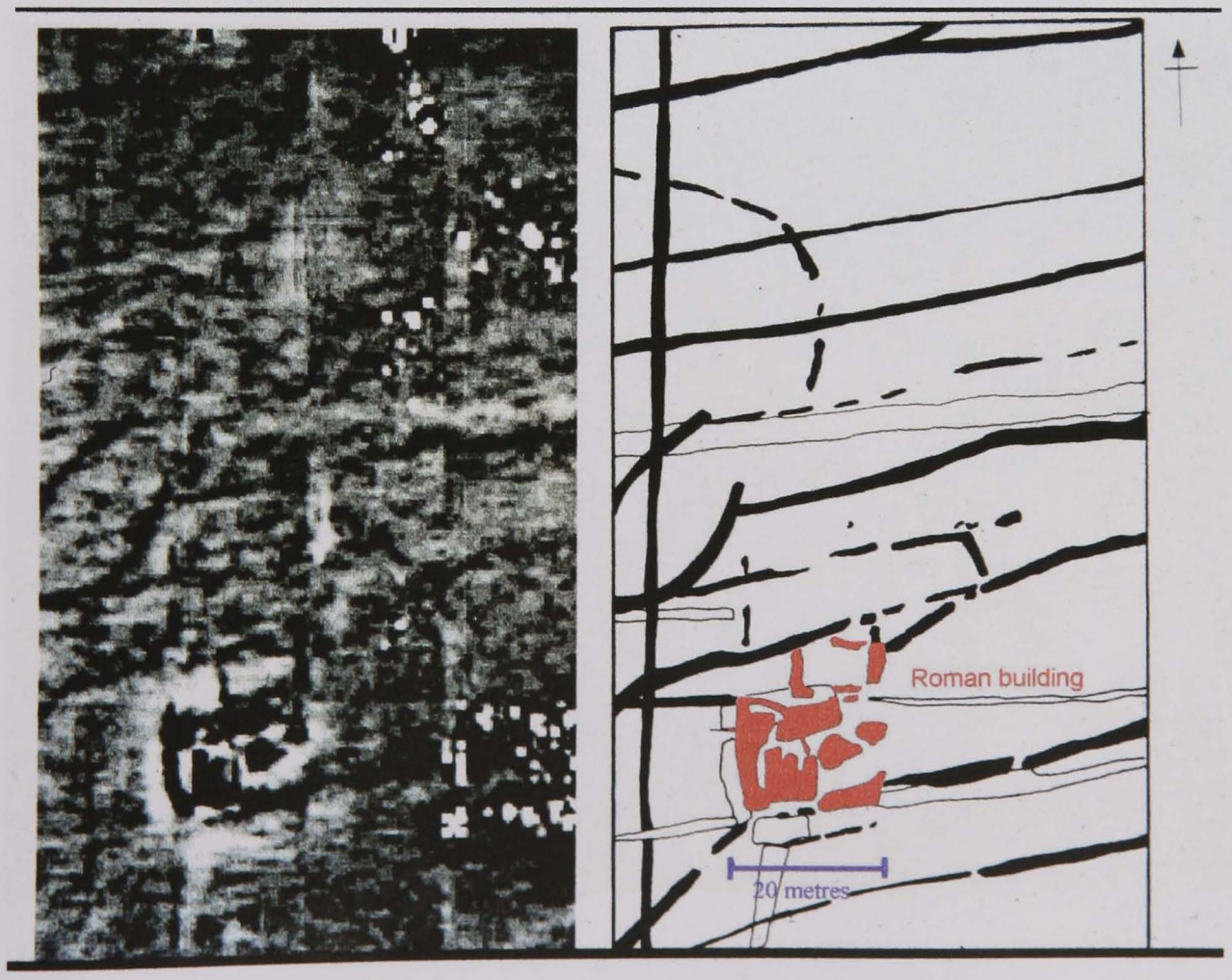


Figure 4.11 **Sladwick, Shapwick Soil Survey Grid**

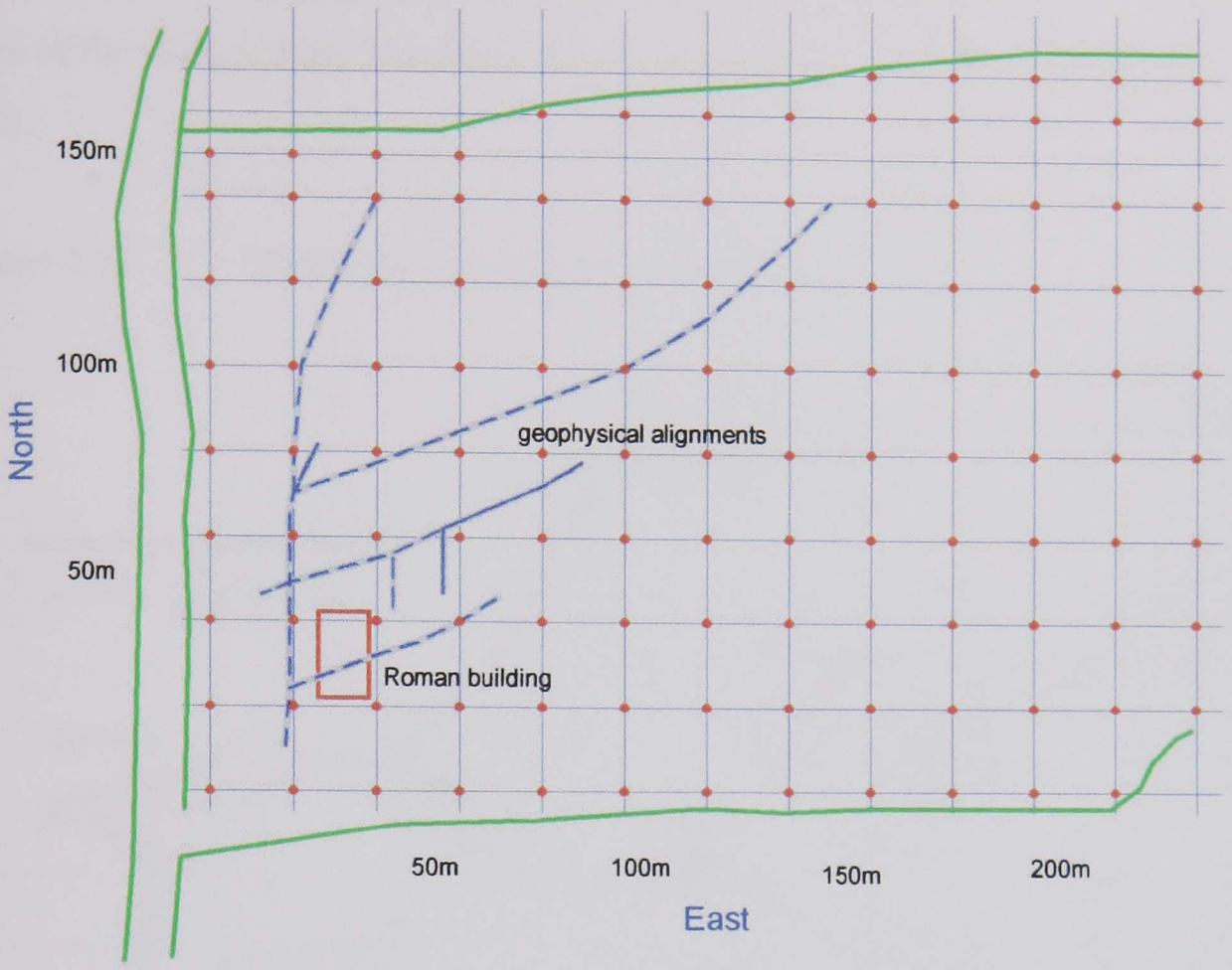


Plate 4.5 **Author (in background) and advisor (in barrow) in southwest corner of "Sladwick" field.**

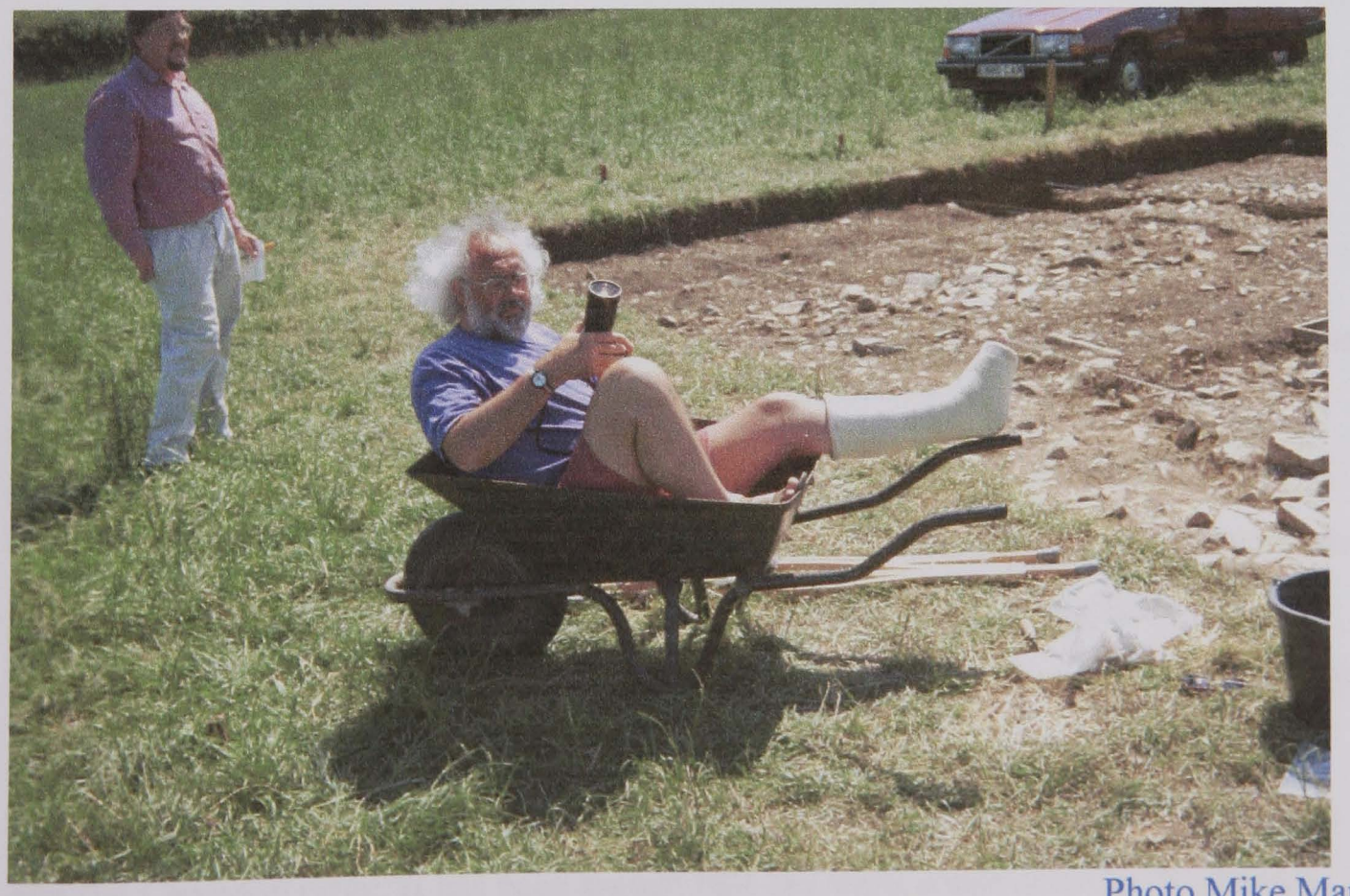
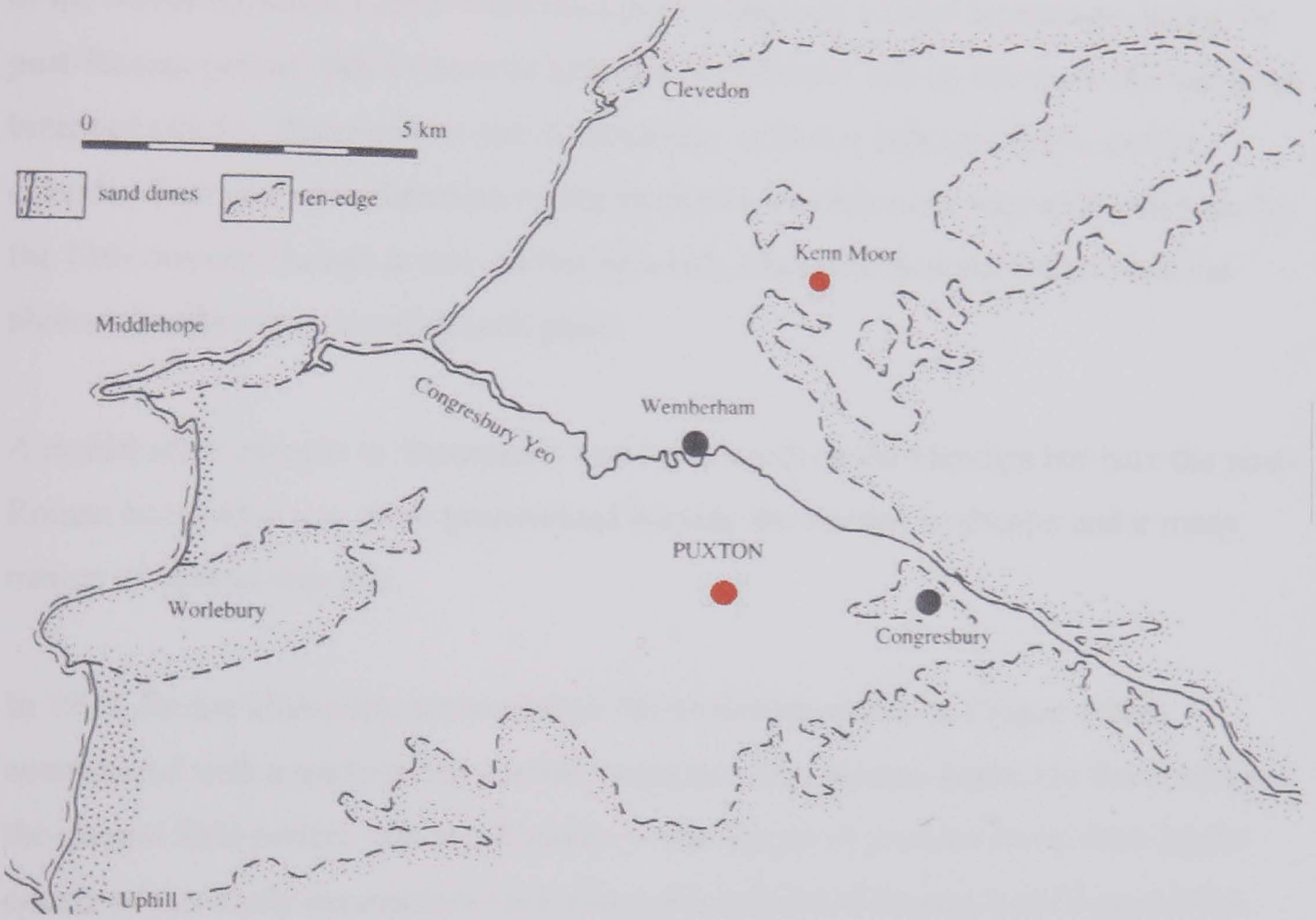


Photo Mike Martin

GROUP B The alluvial lowlands of northern Somerset

Three of the following four sites are located on the North Somerset Levels and to the south of the Congresbury Yeo river, two at Puxton and one close to Kenn (see Figure 4.12).

Figure 4.12 **North Somerset Sites** (after Rippon, 1996)



A fourth site was located on the other side of the Mendip ridge on the levels lying south of the River Axe.

The low lying land that makes up the North Somerset Levels has been protected from inundation from the Severn Estuary by coastal sand dunes (extending from the limestone promontories at Uphill north to that of Worlebury and on to Middlehope) for many centuries and probably as far back as the Roman period. However, there is no evidence that at this early date such natural protection extended between Middlehope and the Clevedon ridge. It has been argued that sea walls constructed in the Roman period may have afforded this protection. The presence of a wealthy late Roman villa on the banks of the Congresbury Yeo at Wemberham would support the hypothesis that the

area north of the river was at that time free from tidal inundation, fully reclaimed and agriculturally exploited. This hypothesis has been confirmed by the results of recent palaeo-environmental work on several Romano-British rural settlements at Banwell (3-4 km south of Puxton), Kenn and Puxton Moors (Rippon 1996; 1997; 1999). The wholly freshwater environment that can be reconstructed on these sites from the pollen, plant macrofossils, mollusca, beetles, diatoms and foraminifera suggests that the stretch of coast, not protected by natural sand dunes, must have been blocked by a man-made earthen embankment. The work at the above sites has also shown that the coastal parts of the North Somerset Levels were once again subjected to tidal inundation during the post-Roman period with a return to saltmarsh conditions: clearly the sea walls had been breached (*ibid.*). Place-names and documentary evidence indicates that a second episode of marshland reclamation on the North Somerset Levels was well-underway by the 11th century, though it was unclear precisely when and how this early medieval phase of settlement expansion took place.

A similar story extends to Somerset's low lands south of the Mendips but here the post-Roman inundation was more pronounced burying the Roman landscape under many metres of alluvial deposits.

In 1993, Exeter University initiated their North Somerset Levels Project which commenced with a study of the partially exposed relict Roman landscape that underlies the present field pattern which is broadly of late-Saxon to post-medieval date. In the course of this study excavations took place at a suspected Roman farm Hamm Farm near the village of Kenn. Soil samples taken from an extensive area around this site were analysed as part of this thesis (see Figure 4.15).

In order to answer the question of when Saxon resettlement took place Exeter University undertook a survey and excavation in 1996 at Puxton some fifteen kilometres south of Kenn in what appeared to be one of the earliest foci for the early medieval reclamation, one of a number of oval-shaped enclosures known as 'infields'. These features are not uncommon on the higher, coastal parts of the reclaimed saltmarshes on both sides of the Severn Estuary, and it has been argued that they represent the earliest stages of marshland reclamation with the oval shape resulting from their having been enclosed in a relatively open landscape and so were unconstrained by existing landscape features (Rippon 1997, figs. 44 & 45). The sites have a number of common characteristics. They are often associated with field-names indicative of early medieval habitation (e.g. 'worth' and 'huish'), lie close to medieval churches/chapels,

and have surface finds of medieval and/or Roman pottery. Many are also associated with extant farmsteads, though like the churches/chapels, these almost invariably lie on the edges of the enclosed area.

The University of Exeter site at Church Field (and an adjoining field), both close to centre of the village of Puxton, were sampled before the commencement of this present study (see Figure 4.16) and the results of the initial analysis are reported elsewhere (Jackson, 1997). Nonetheless, in the light of new archaeological information the data have be re-assessed and the new analysis included in this report. A new field half a kilometre to the east of Puxton bearing a field name (*Hardingworth*) suggestive of early settlement was added to the soil analysis programme (see Figure 4.16). Quite separate from the Exeter University survey an investigation was initiated into part of a sub-circular field pattern at Vole south of the Mendips in the central Somerset Levels just to the east of Brent Knoll (see Plate 4.7).

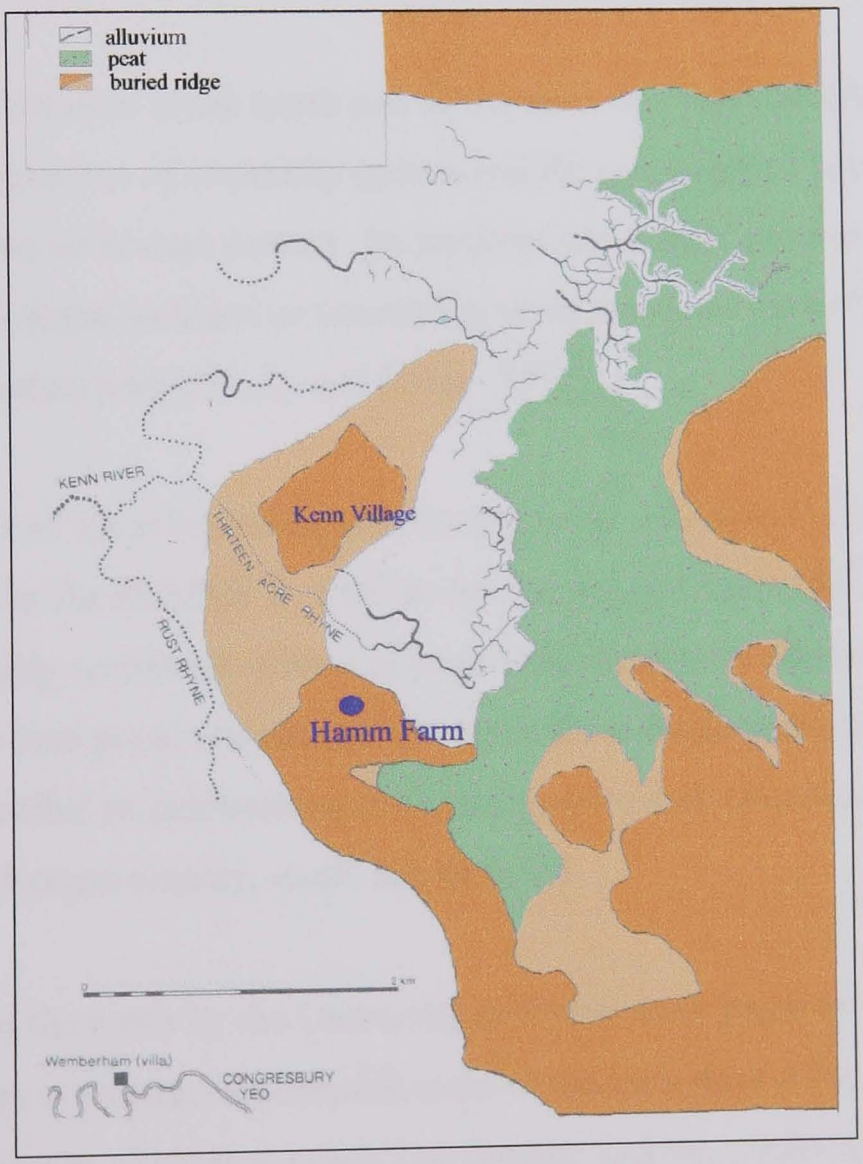
SITE FOUR

Hamm Farm (*aka* Kenn Moor)

SITE DETAILS: Hamm Farm, where most of the sampling took place, consists of flat mixed-arable land set just above the 5m contour. The present farm buildings with the south-western half of the survey area sit over a ridge of Triassic Keuper Marl[67] submerged beneath a layer of estuarine alluvium (blue clays) and alluvial silts. These deposits from past marine incursions deepen towards the north east as the "bedrock" dips under a peat filled Kenn Moor. The hidden Keuper Marl ridge extends a kilometre or so north to a relict sand and gravel shoal (Burtle Bed) upon which sits the present village of Kenn (see Figure 4.13).

Figure 4.13 **Geology of the area surrounding Hamm Farm**

(after Rippon, 1995)



Most of the soils sampled (taken predominantly from the half dozen or so fields of archaeological interest) were acid to neutral (pH 4.6 to 6.0) pale grey silts, but redder, more alkaline soils (pH 6.0 to 7.5) were noticed particularly in fields east of the

---

[67] The Keuper Marls or Mercian Mudstones "so-called" are often comprised of silty mudstones intermixed with thin sandstones.

farmyard. Indeed this band of alkaline soils, consistent with the underlying geology, stretches north towards Kenn village. However, soils from a group of three fields in the supposedly deeper alluvial north east of the sample area also proved to be alkaline. No geological/pedological explanation was forthcoming. It is possible that agronomic factors may have had more influence on the soil as four of the five the fields demonstrating the more acid soils were long term pastures with little or no recent arable history. It was within these fields that earthwork evidence of past settlement survives.

ARCHAEOLOGICAL BACKGROUND: In search of a well preserved Roman site to establish the chronology and activities that preceded the post-Roman inundation, the University of Exeter settled on a partially exposed relict landscapes lying to the north and to the east of Hamm Farm (see Figure 4.14).

Evidence of settlement at the north end of the farm was first identified in the 1950s when the construction of electricity pylons and the re-cutting of field ditches both revealed scatters of Roman pottery. Subsequent small scale excavations uncovered two burials, a small stone wall and an interesting stone structure (described as a corn dryer) all from the Roman period (Lilly and Usher, 1972).

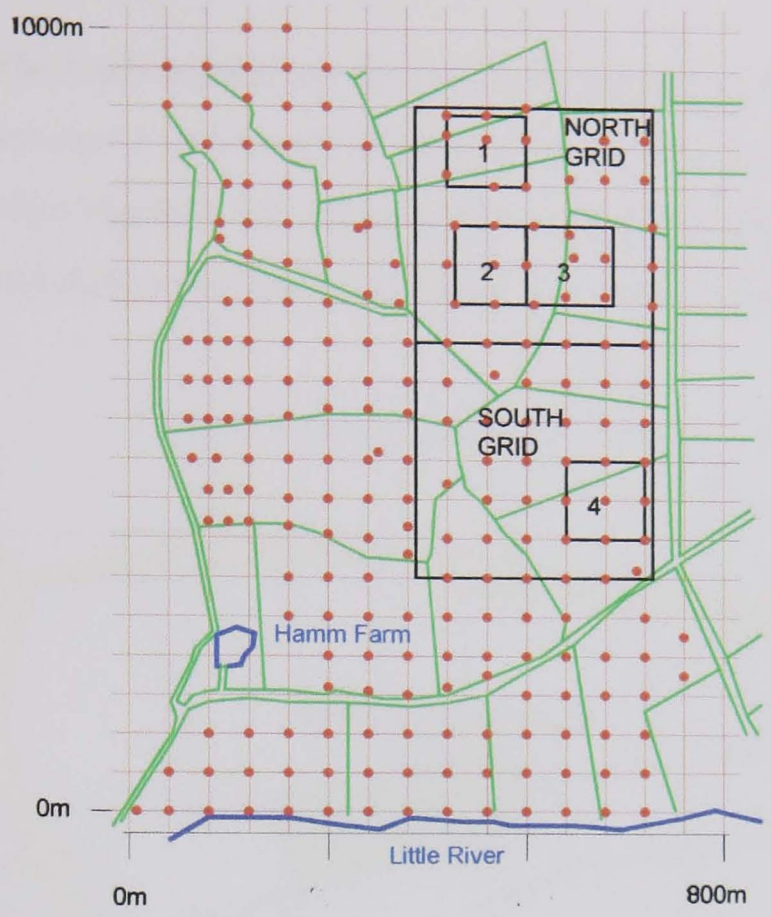
The major part of the relict landscape, starting some 500 m to the east of Ham Farm, was surveyed by the RCHME in 1993 at the request of Exeter University and an irregular, roughly rectilinear system of large enclosures with internal sub-divisions were recorded. The best preserved earthworks lay in three fields under permanent pasture an were not accessible to fieldwalking or for excavation and, consequently, though suggestive of Roman activity, could not be dated.

Excavations in the north by the University of Exeter took place in 1994 and 1995. The first years work confirmed the identification of the corn drier relocating the furnace and recovering deposits of charred grain. The furnace and the earthworks surrounding the drier abutted, on its northern edge, a relict palaeo-channel which may have been a small creek at that time. Some third and fourth century pottery was recovered but the general paucity of sherds suggested that the drier lay on the margins of the settlement.

igure 4.14 **Earthwork Survey of Hamm Farm** (Rippon, 1994)

Excavations by the University of Exeter in 1995 concentrated on the field immediately to the south of the corn drier. Various ditches and gullies with associated charcoal, burnt clay, bone, Roman pottery and stone scatters were recovered. A trench in the field to the east revealed a concentration of Roman midden material and a thin layer of green silt that was tentatively identified as cess suggesting the possible focus of the settlement. During both seasons, fieldwalking was carried wherever fields had been ploughed. Roman material was recovered from a wide area surrounding the site of excavation. Trenches were also dug into longitudinal elements at the periphery of and associated with the earthworks in the inaccessible fields to the south. These produced third century Roman material but no confirmation of any structures.

Figure 4.15 **Hamm Farm Sampling Grid (50m)**



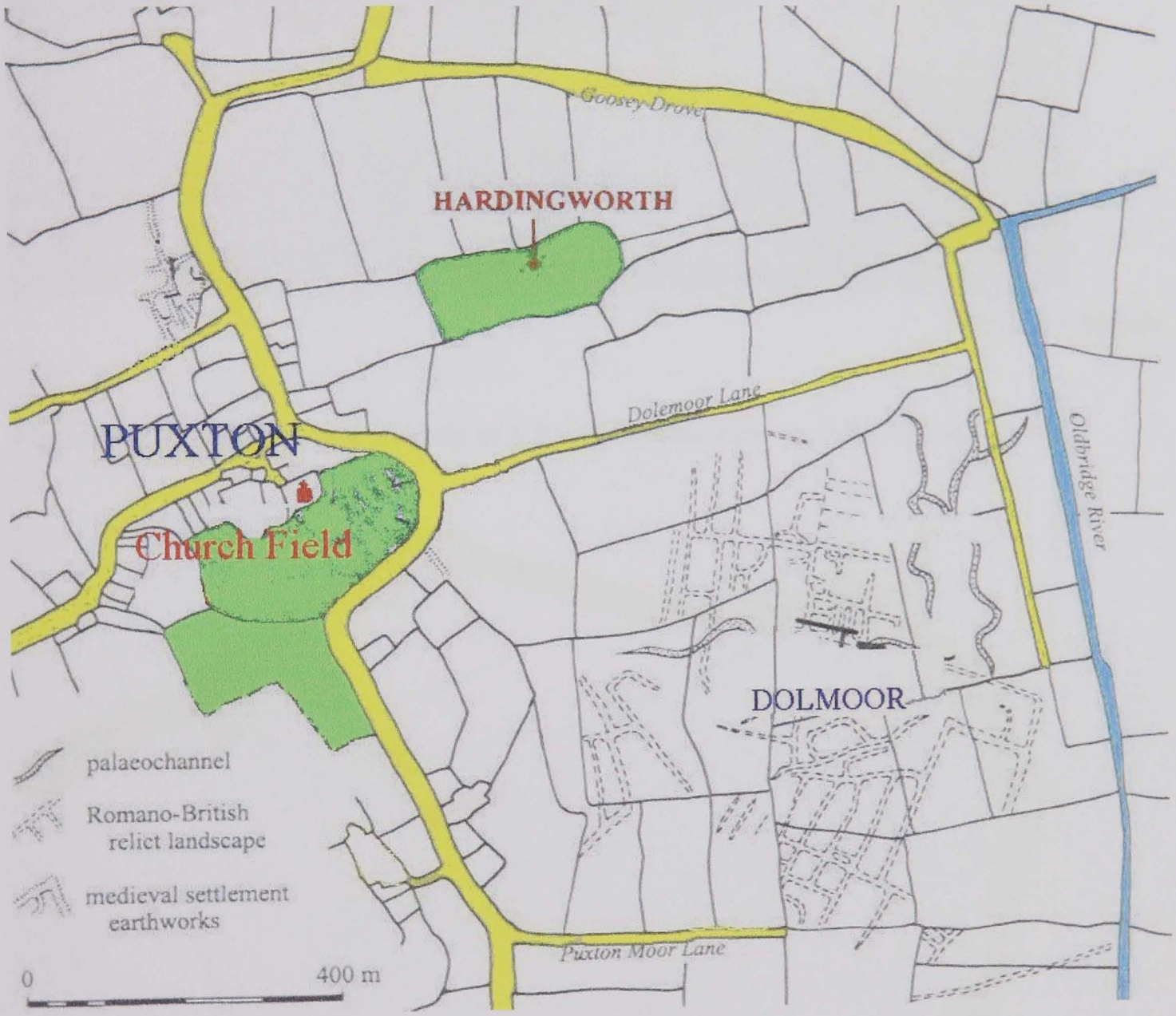
Sixty hectares of farmland extending over Exeter University's excavation and field walking sites as well as the southern pastures were soil sampled on a 50 m grid in 1998. Within this area a selected 18 ha were sampled at twenty metre intervals and within this 4 ha were sampled at ten metre intervals (see Figure 4.15 above).

SITE FIVE

Puxton "Church Field"

SITE DETAILS: The fields studied are flat and lie on sequential deposits of slightly acid alluvial clays just over 5 metres above sea level at the western edge of the marshy peat rich Dolmoors (see Figure 4.16). Much of the surrounding land is under long term grass, the better drained soils occasionally cultivated and sown to cereals or other break crops.

Figure 4.16 **Puxton Village Sites** (after Rippon, 1999)



ARCHAEOLOGICAL BACKGROUND: 'Church Field' lies near the centre of Puxton (see Plate 4.6), a village 5 km to the south of Hamm Farm (see Figure 4.12). The site has been subjected by the University of Exeter to earthwork (Figure 4.17), resistivity (a limited area south of the church -Figure 4.18) and fieldwalking surveys (Figure 4.19), along with three trial excavations (Rippon 1996; 1997; 1999). In 1996 soil samples were taken from the field together with a field to the south (see Figure 4.18). Puxton conforms to the type description of an 'infield' with a church and hamlet located on its

Plate 4.6 **Aerial photograph of Church Field, Puxton**

Photo: S. J. Rippon

Figure 4.17 **Earthwork Survey of Church Field, Puxton** (after Rippon, 1996)

northern edge, though there is no evidence for a habitative field-name. When ploughed during the 1960s, the field revealed Romano-British and medieval pottery (see results of later fieldwalking by the University of Exeter - Figure 4.19) and, though considerably denuded by recent ploughing, there survive the earthworks of a coherent pattern of rectilinear platforms and enclosures suggestive of an area of abandoned settlement (see Figure 4.17).

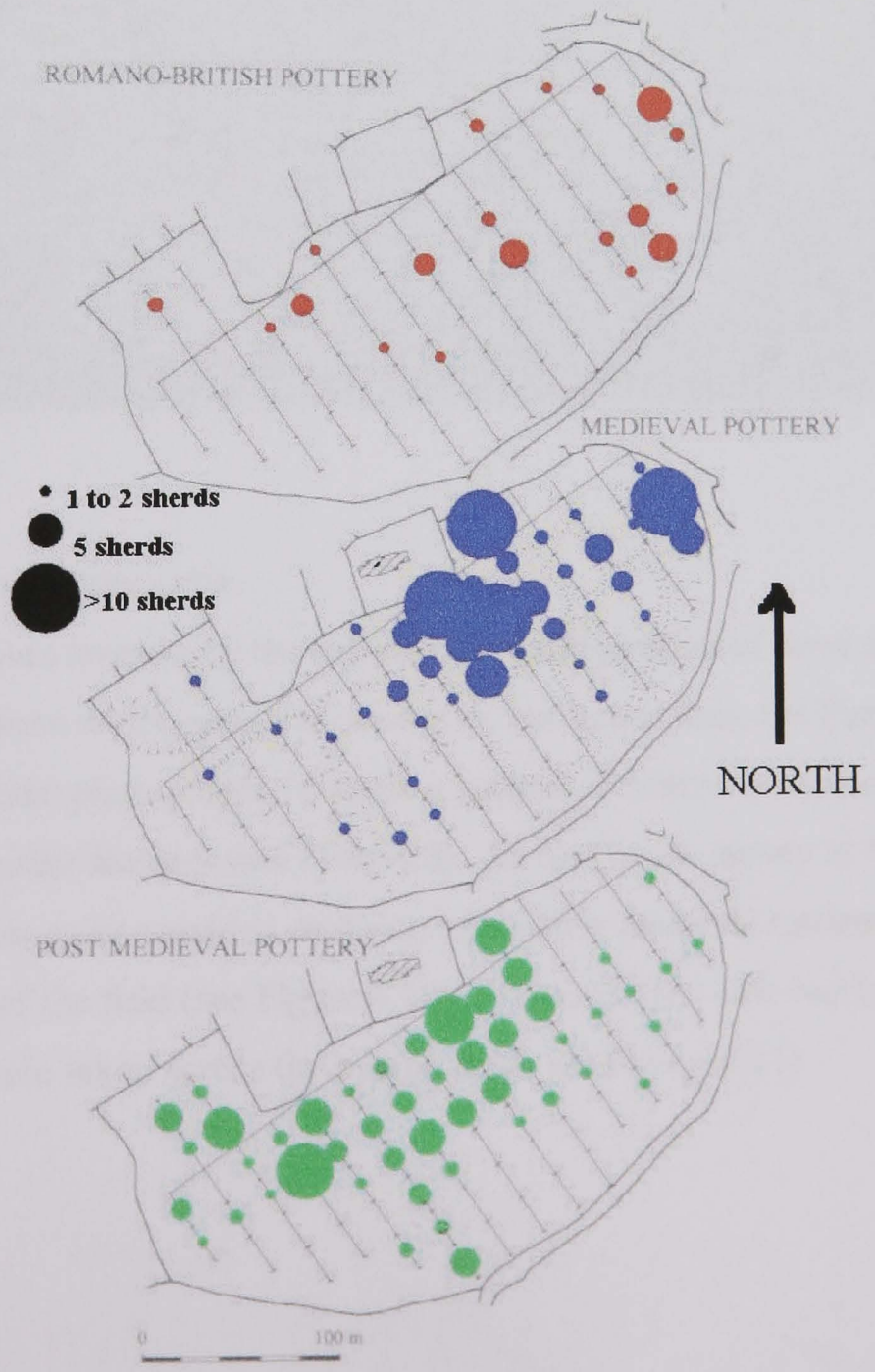
The smaller but more pronounced platforms lay to the north/north-east of the 'infield' and are suggestive of house platforms, the highest of which lies immediately to the south east of the church. Although under pasture for many years, Church Field was ploughed subsequent to completion of the initial excavations. Follow up fieldwalking and the soil analysis results led to further excavation. Initial excavation had revealed a deep sequence of occupation debris dating to between the 10th and 13th centuries. The enclosures in the southern and western parts of the 'infield' are larger and defined by slighter ditches, and are more suggestive of the paddocks that cluster around traditional farms even today, being used as gardens, orchards and yards for livestock. The fieldwalking survey produced a light scatter of medieval material suggestive of kitchen rubbish and farmyard manure being spread over the paddocks in order to increase fertility. To the south west of the church there is a pronounced circular depression which, when fieldwalked, yielded large amounts of post-medieval material suggestive of a former pond that has been partly backfilled in recent times. The eastern, southern and western edges of the 'infield' enclosure are marked by an extant field drain, inside which there are traces of a concentric bank and inner ditch.

The University of Exeter fieldwalking survey also produced Romano-British and post-medieval pottery (see Figures 4.19). The former was a very light scatter over much of Church Field, indicative of no more than the spreading of farmyard manure over fields. Larger amounts of post-medieval pottery were recovered concentrating in the northern and north western areas, indicative of manuring and the dumping of material over the ends of back gardens in the extant village. A very discrete concentration of post medieval debris also occurred in and around the slight depression of a former pond and indicates its recent partial back-filling.

Figure 4.18 Resistivity Survey of part of "Church Field, Puxton

(Scale –1 sd white, +1 sd black) - Rippon, pers.com.

Figure 4.19 **Field walking Survey of "Church Field", Puxton** (Rippon, 1997)



SITE SIX

Vole

SITE DETAILS: The area sampled was a relatively level and low lying field (area: 4 ha elevation: 5-10 m above mean sea level)) adjoining Knoll View Farm at Vole (14 km south of Puxton) in south Somerset (see Plate 4.7). The field was under long term grass and lies over several metres of estuarine alluvium. The nearest source of modern pollution is the M4 motorway lying 1.5 km to the west (see Plate 4.9).

Plate 4.7 **Aerial view of Knoll View Farm**

Photo: Jim Jones

ARCHAEOLOGICAL BACKGROUND:

Interest in the site was aroused by the sub-circular configuration of three adjoining fields abutting the farm which appeared similar to, but larger than, the Puxton *infield* (see page 156). Aerial photographs revealed a pattern of relatively modern drainage ditches overlying earlier features (see Plate 4.8). An earthwork survey in 1998 by Jim Jones of Bristol University provided evidence of possible medieval settlement at the north western end of the field (see Figure 4.20). Although little else was known of the site, soil samples were taken across the middle field (see Figure 4.21).

Plate 4.8 Aerial view of the Vole " in-field". (Sampled field highlighted).

1947 aerial photograph provided by Jim Jones

Figure 4.20 Earthwork Survey of the middle field at Vole (after Jim Jones)

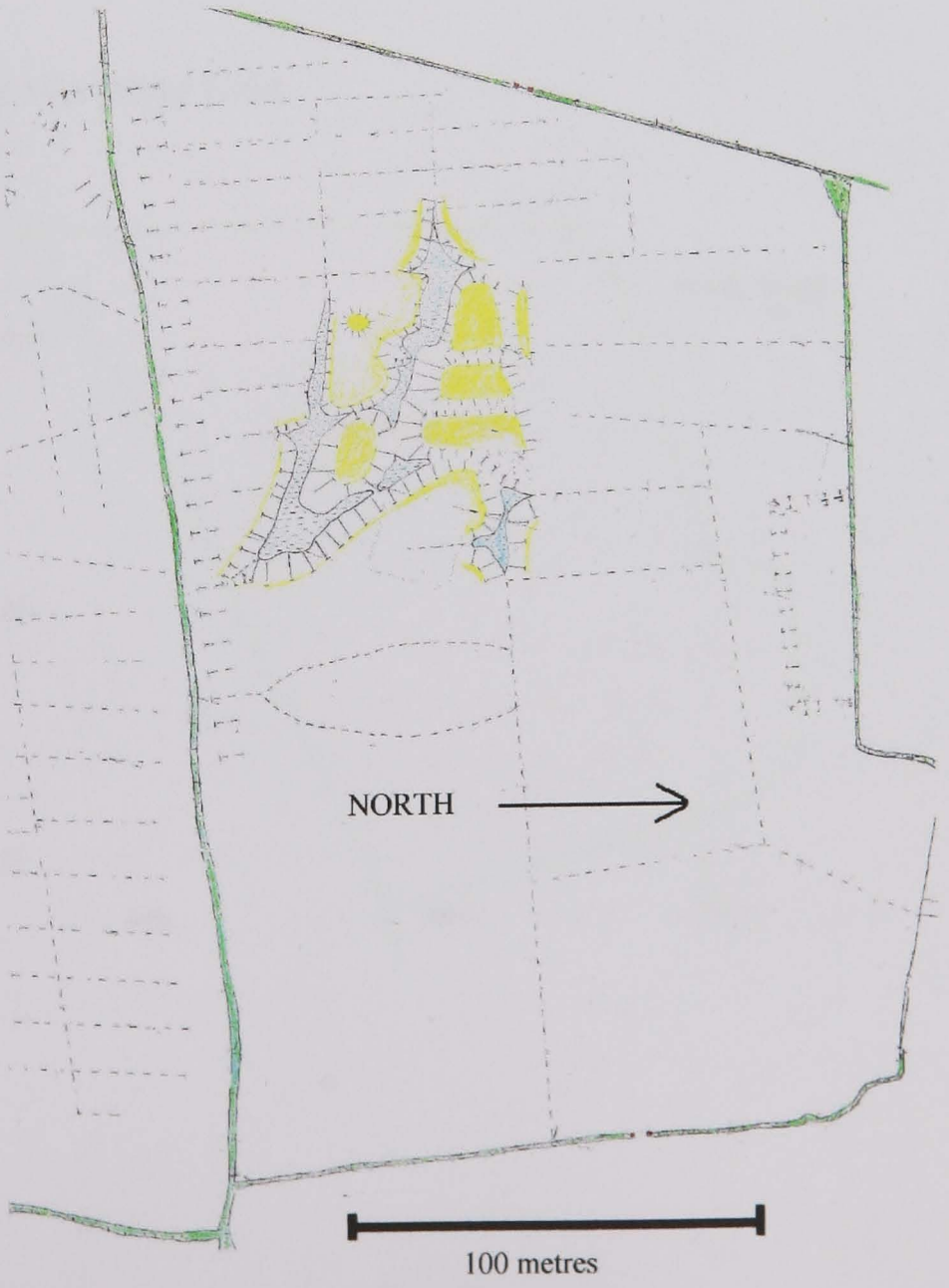
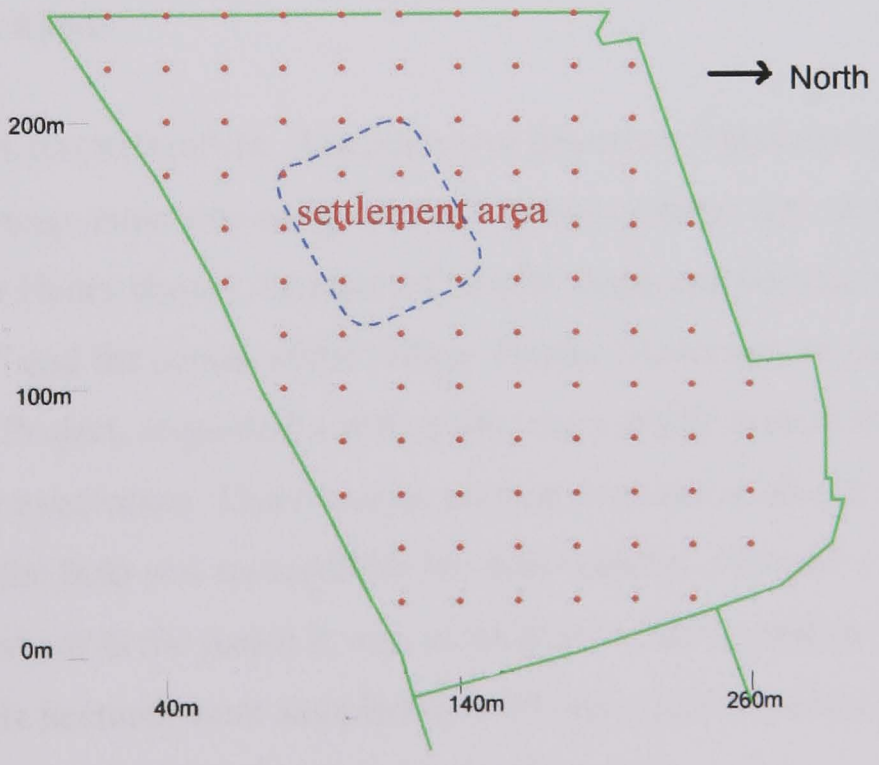


Plate 4.9 **Vole " in-field" looking west towards the M4 motorway (not visible) and Brent Knoll.**

Photo M. A. Aston

Figure 14.21 Vole Sampling Grid



SITE SEVEN

Puxton "Hardingworth"

SITE DETAILS: The area surveyed included the whole of Hardingworth Field with parts of seven adjoining fields covering, in total, 6 ha. The fields are all flat and low lying (below the 5m contour line) and bounded by drainage ditches or *rhynes*. All are under long term pasture and the soils are uniform, slightly acid (pH 5.8) tidal alluvium.

Plate 4.10 **Aerial view of Puxton village and "Hardingworth"**

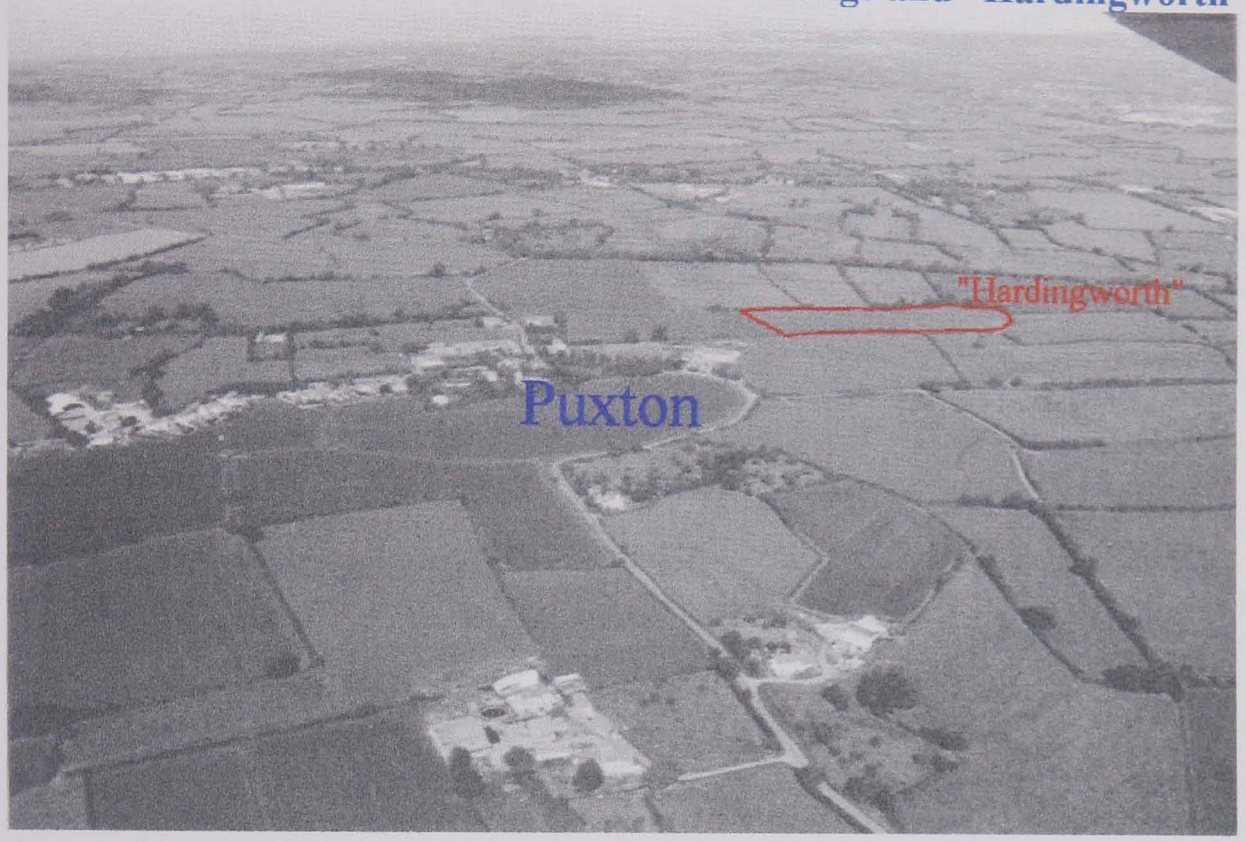
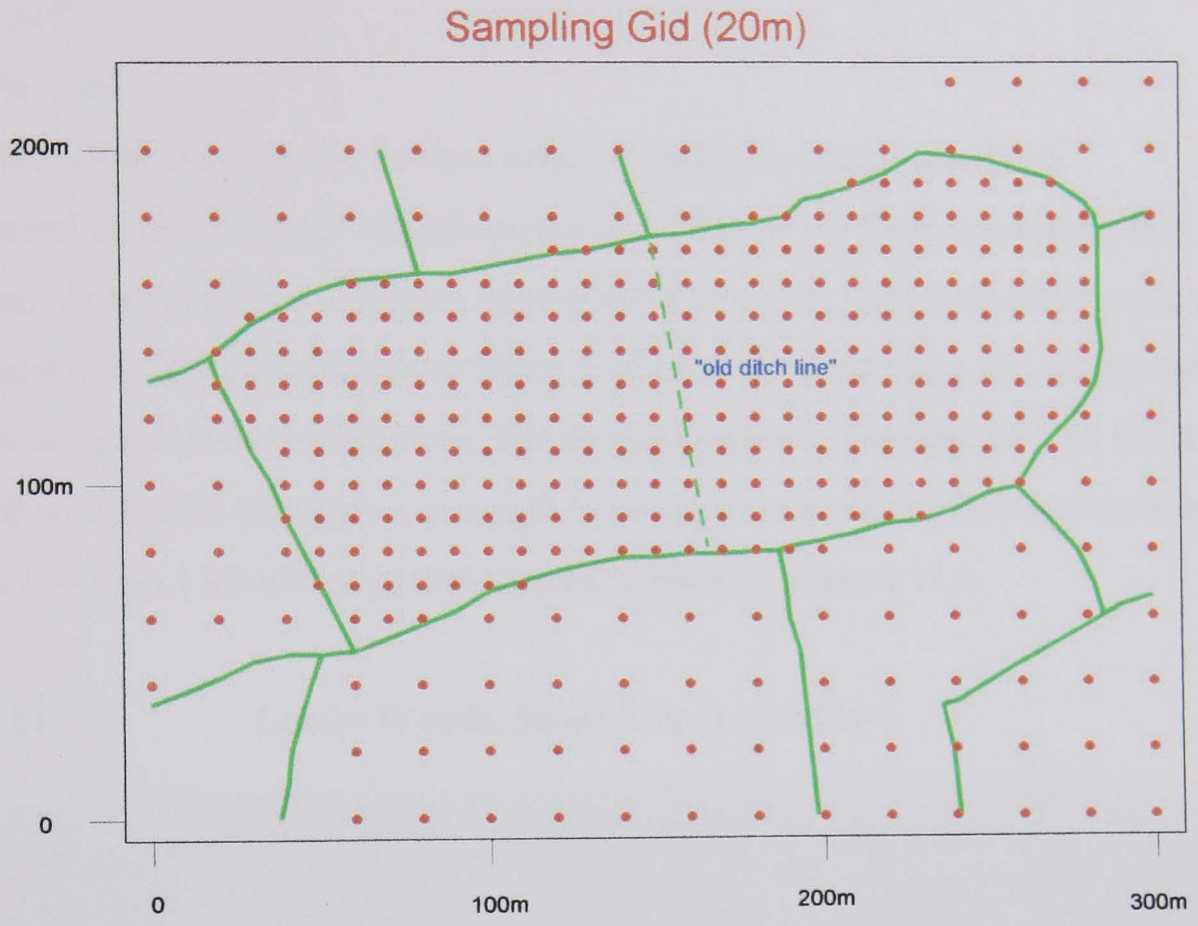


Photo: S. J. Rippon

ARCHAEOLOGICAL BACKGROUND: Attention was drawn to "Hardingworth" field because the tithe map name was comprised of a personal name with an early settlement suffix (*wyrδ* – see Henry above), because of its odd shape and because of its proximity to "Church Field" and the centre of the village. Exeter University, as part of their North Somerset Levels Project, requested a soil survey and analysis in an attempt to locate potential sites for excavation. There was no surface evidence at all and, being under long-term grass, the field was un-available for field walking. Because of the success of soil analysis elsewhere in the parish it was decided to try the techniques as a primary surveying tool. Six hectares were sampled on a 20 metre grid covering the whole of "Hardingworth" and parts of eight other surrounding fields.

Figure 4.22 "Hardingworth" Sampling Grid



GROUP C Woods and woodland edge

The following two sites are Roman and post-Roman settlements in or surrounded by woodland.

SITE EIGHT

Lower Woods

Lower Woods lie beneath the western edge of the Cotswolds in southern Gloucestershire and some 17 -18 kilometres inland from the Severn Estuary. The woodland shows evidence of human management since the early medieval period and was almost certainly part of a wider forest landscape in which there are indications of far more ancient human exploitation. The woods currently comprise of 288 hectares of managed woodland 3 kilometres in length tapering from a width of 2 kilometres in the north to less than 1 kilometre at their southern end (see Plate 4.11).

Plate 4.11 **Lower Woods, South Gloucestershire**

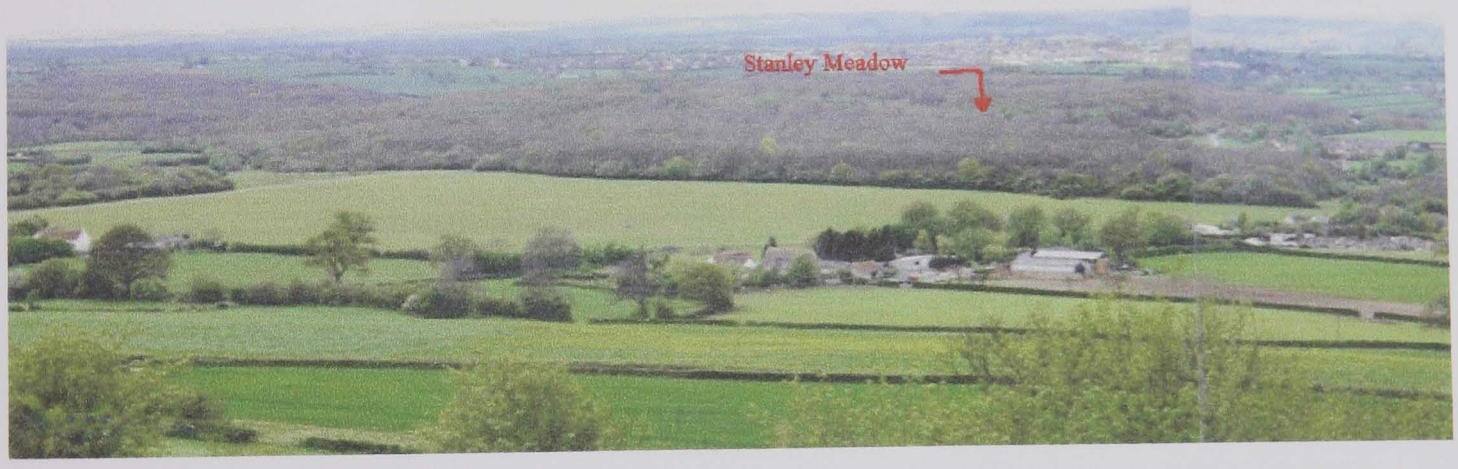


Photo: A. W. Jackson

SITE DETAILS:

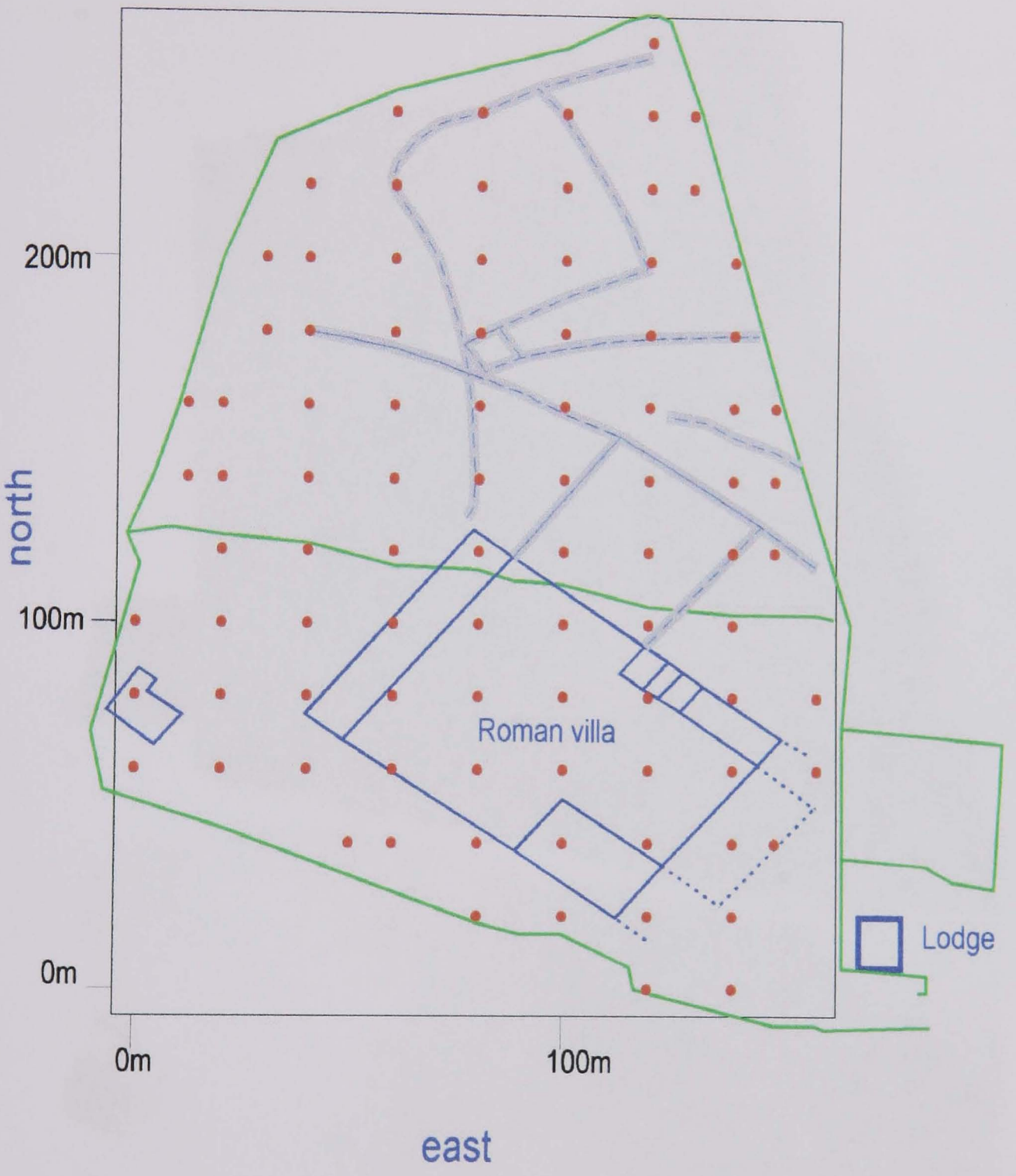
The whole of Lower Woods has been cleared for coppicing at some stage in the last hundred years, the last extensive clearance being in 1948 and coppicing continues until this day. Some areas cleared in the 1880s were left as grassland for upwards of 70 years before replanting. However, two adjoining areas of open grassland, Stanley Meadow and Stanley Orchard set in the middle of the northern end of Lower Woods (see Figure 4.23), have remained so for at least five hundred years and may have treeless for much longer. These fields comprise of approximately 3 ha of ancient meadow and are enclosed an all sides by managed woodland. The soils are slightly acid clay loams.

Figure 4.23 Lower Woods, South Gloucestershire (after M. Martin, pers.com)

ARCHAEOLOGICAL BACKGROUND: The woodland and area surrounding Stanley Meadow and Stanley Orchard became subject of an MA project studies in 1997 (Jackson, 1997), during the course of which the recovery of several Roman pottery sherds from holes dug for fencing were reported. A subsequent search of the exposed surfaces of wood banks and disturbed soil around badger sets recovered many more sherds dating from the first century BC to the fourth century AD. Most were concentrated close to the Lodge House and along the eastern edge of the Stanley meadows. Roman material far and away predominated with little or no pottery of a later date being recovered. The name of the two meadows, "Stanley", indicated the previous existence of a stony (*stan* …a stony outcrop, a standing stone or a source of building stone?) clearing (*ley*) in the wood. There are no outcrops of rock, standing stones or visible surface evidence of ancient buildings today, nor any earthworks to suggest past settlement.

It was decided to take soil samples from these two meadows in search of evidence for past activities that might be associated with the pottery finds (see Figure 4.24).

Figure 4.24 Stanley Meadow Sampling Grid

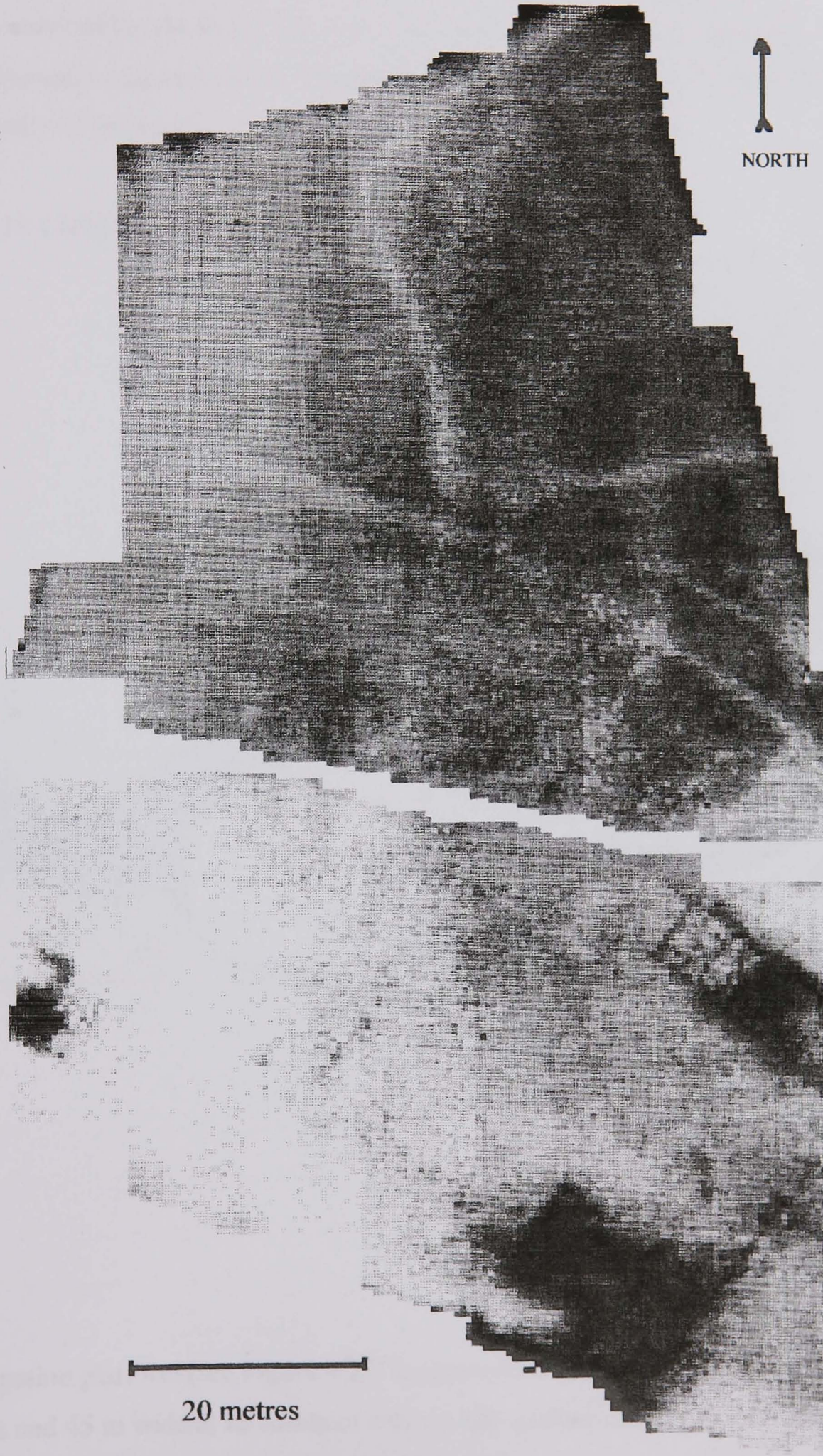


[Samples were also taken from within Crew's Coppice which lay to the east of the meadows. In addition plant material (grass or Dog's Mercury) was sampled on the same grid and also assessed for indicative elements. Further soil samples were taken from the longest standing piece of woodland (Wetmoor) half a kilometre to the south to provide some additional comparative data. These data are not reported in the main body of this dissertation – see CD]

Subsequent to the soil analysis the two meadows underwent a resistivity survey and a Roman settlement was discovered (see Figure 4.25).

Figure 4.25 Stanley Meadow Resistivity Survey

(Scale: -1 sd white & +1 sd black)



Martin, Martin & Jackson (unpublished)

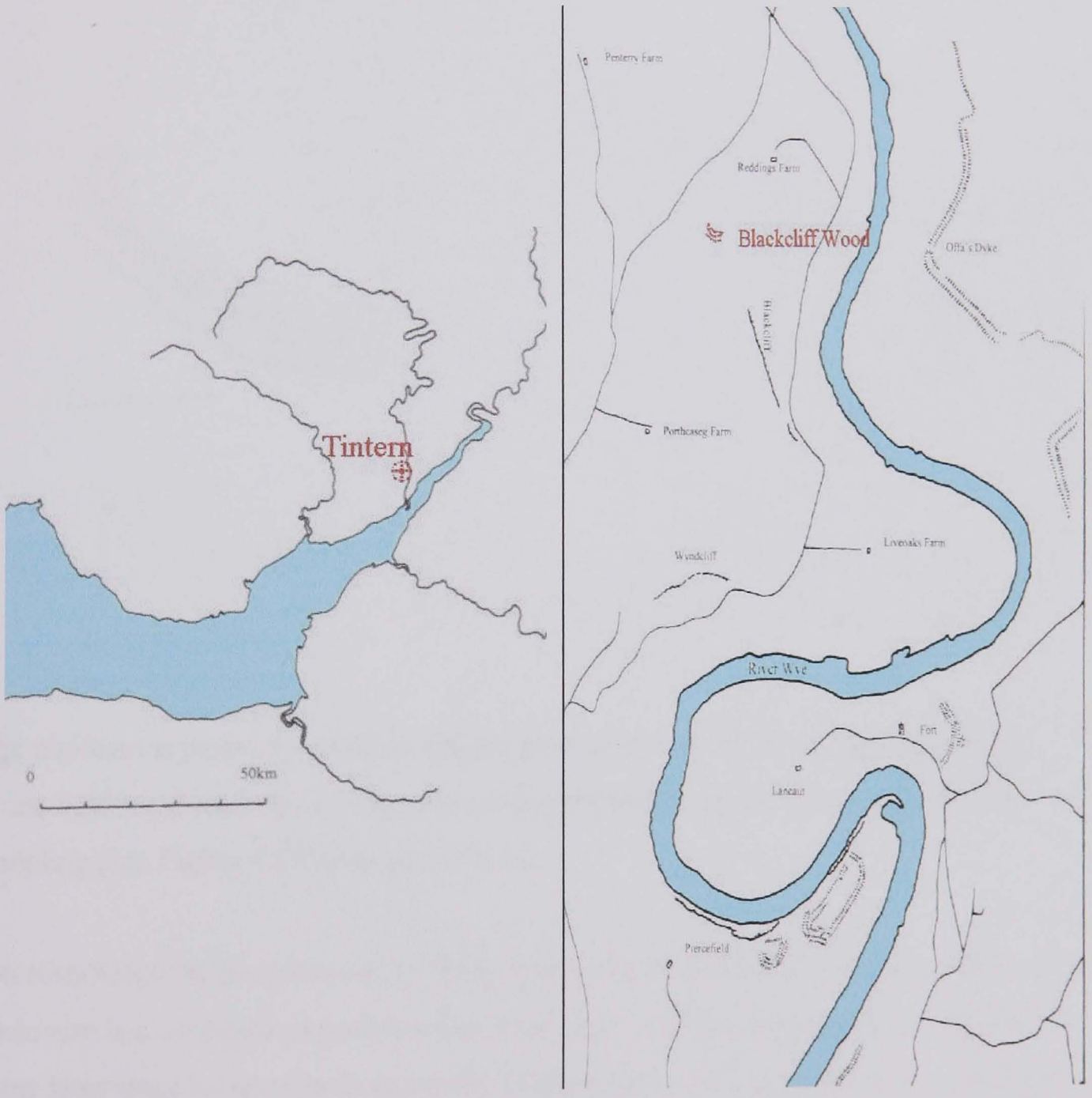
SITE NINE

Blackcliff Woods

SITE DETAILS:

The enclosed settlement in Blackcliff Wood is situated on a narrow ridge tapering to the north and overlooking the River Wye near Tintern in Monmouthshire, Wales (see Figure 4.26) and comprises of one of several sites investigated by Dr. Andrew Eden of the University of Bristol.

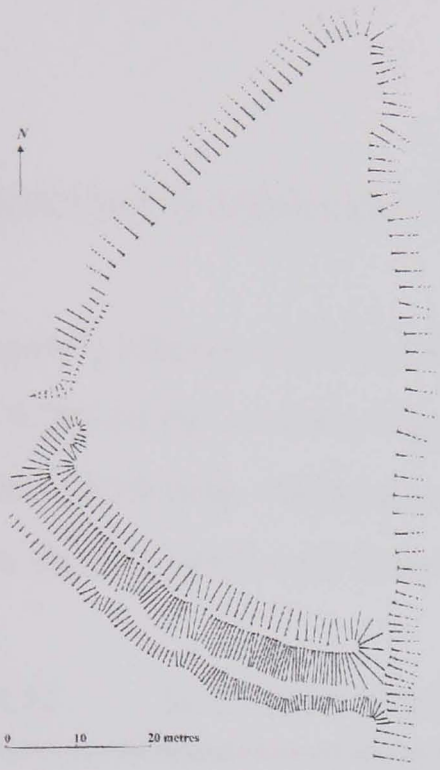
Figure 4.26 Location of Blackcliff Wood Settlement (Eden, 2000)



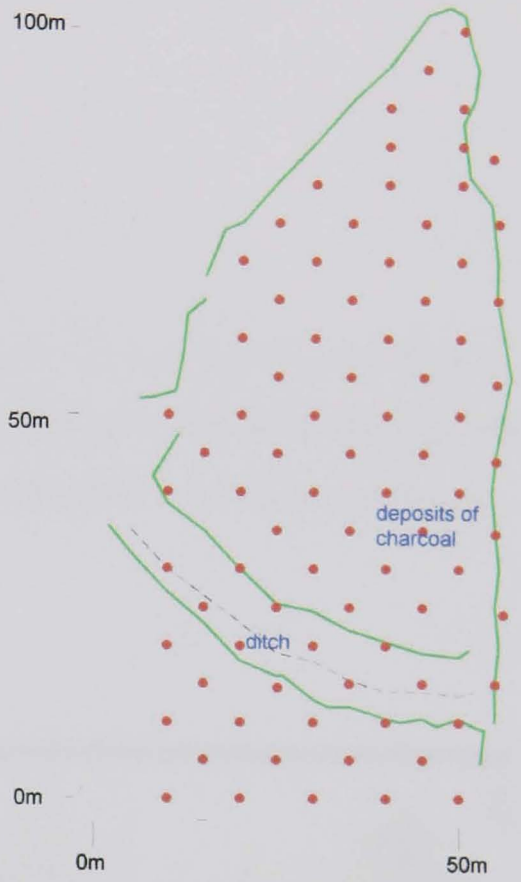
The occupation platform (see Figure 4.27) is approximately 80 m long on its north-south axis and 45 m wide at its southern end. At this southern edge it is bound by a stone bank and deep ditch, both of which curve around to what was probably the main

entrance, i.e. on the western side. The bank continues a further 10 m beyond the 'entrance' in a northerly direction. Where there is no bank the ridge falls steeply away.

Figure 4.27 Earthwork Survey (Eden, 2000)



4.28 Sampling Grid



The platform is presently wooded making most geophysical surveying impractical. Some field measurements of magnetic susceptibility had been taken before the soil sampling (see Figure 4.28) was undertaken.

ARCHAEOLOGICAL BACKGROUND: There is very little known about the site. The enclosure is a conjectured post-Roman "Dark Age" settlement possibly occupied at some later stage by hermits from nearby Tintern Abbey (Eden, pers. com.). Eighth to tenth century Saxon metalwork has been found close by but no other artefacts, other than a single flake of knapped flint (undated) and several pieces of iron slag have been recovered from within the site (Eden, pers. com.). The site has never been excavated.

The last three sites are fields associated with two Medieval religious settlements, one settlement (two sites) at Kirkdale in North Yorkshire and the other at Kinaleghin in County Galway in the Irish Republic.

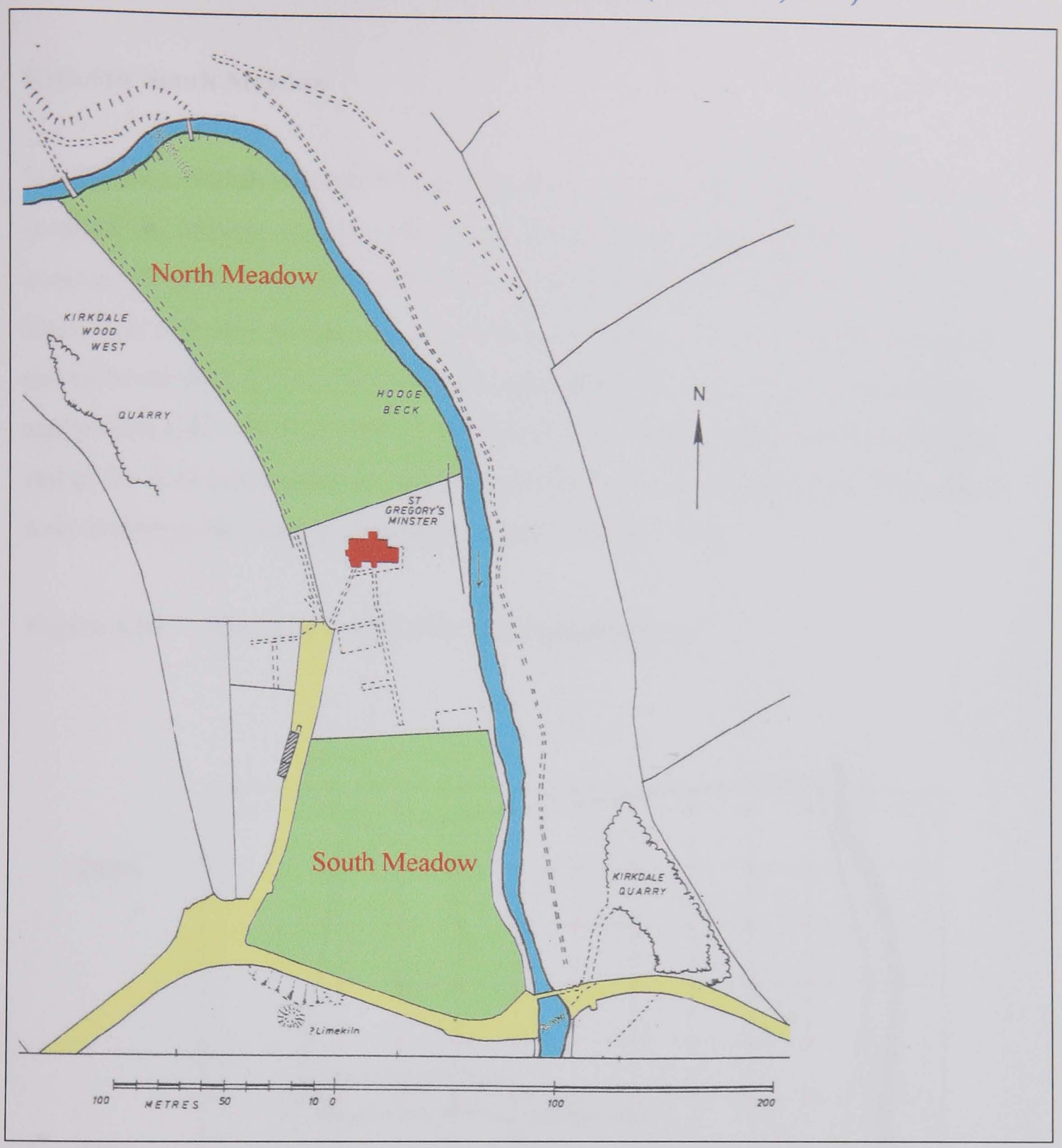
ST. GREGORY'S MINSTER, KIRKDALE

St Gregory's Minster (see Plate 4.12) sits on the narrow flood plain of Kirkdale (see Figure 4.29) on the southern edge of the North York Moors overlooking Ryedale and the Vale of Pickering. Although now a small and remote church it is believed it once was the site of a small early Saxon monastery.

Plate 4.12 St Gregory's Minster, Kirkdale.

Photo M. A. Aston

Figure 4.29 **St Gregory's Minster, Kirkdale** (Watts *et al*, 1998)

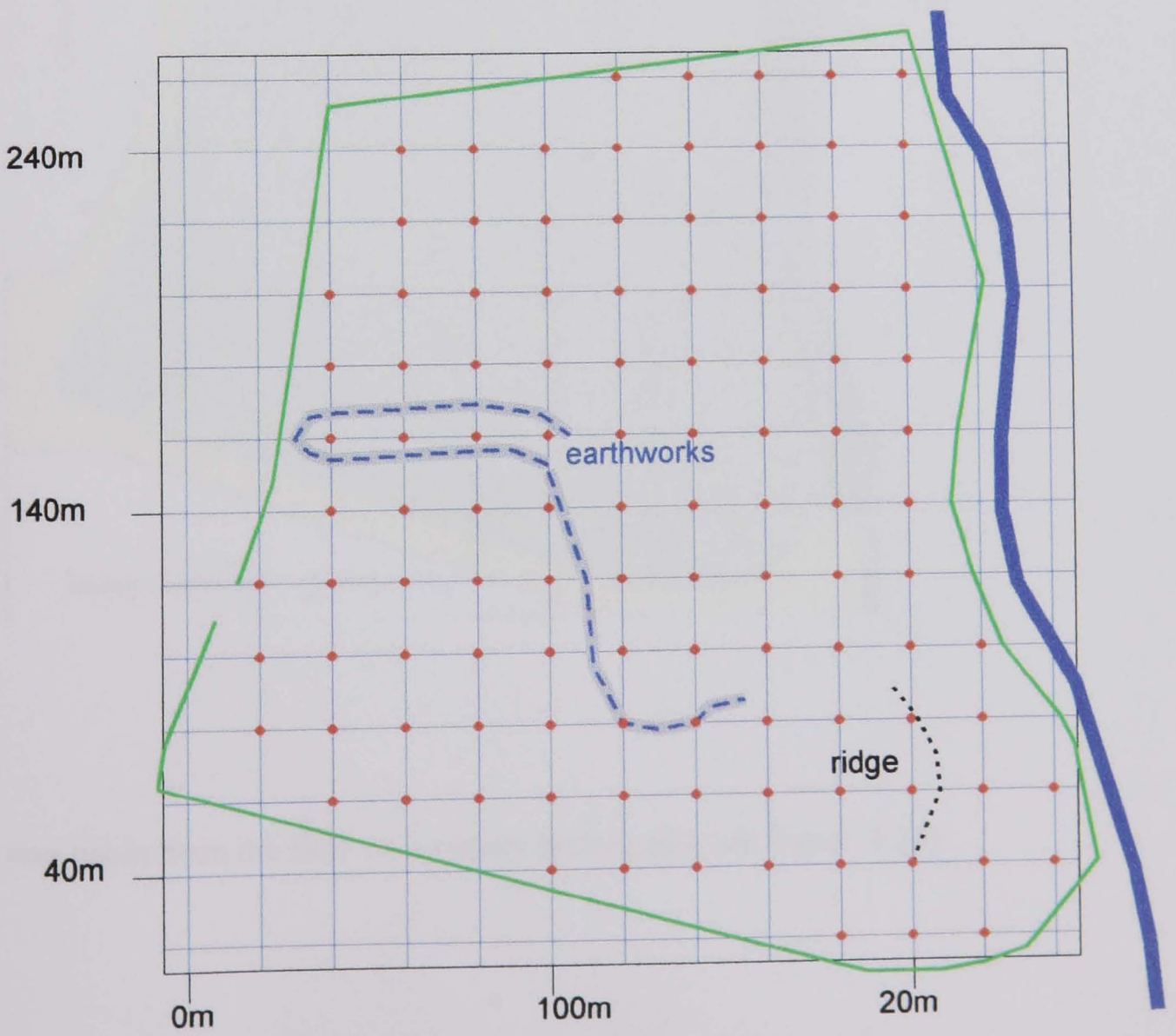


In 1994, concerns about the fabric of the old church led to an examination revealing several hitherto unrecorded features. This in turn stimulated the University of York and the local archaeological society to take up a more detailed study of the Minster and its immediate vicinity. Under the general supervision of Phillip Rahtz and Lorna Watts earthwork surveying, geophysical prospection and excavations were initiated. The results went some way to confirming the theories about the site and the work is continuing. A soil analysis survey of two meadows on either side of the churchyard was able to add even more information.

Kirkdale South Meadow

SITE DETAILS: Kirkdale South Meadow is a little over a hectare in size, situated to the south of the Minster and north of the old turnpike road. Lying just below the 50m contour, the field drops several metres from the lane on the west down to the Hodge Beck. The soils vary in depth (up to 1.5m) and consist of a diverse mixture of alluvial and colluvial deposits but comprise predominantly (and surprisingly) of acid, plastic sandy-clays (pH 4.8). An old flood plain scarp extends diagonally from the northwest end of the field outcropping (Corallian limestone) in the southeast corner. The thinner soils overlying the outcrop were fairly neutral (pH 5.5 – 6.0).

Figure 4.30 Kirkdale South Meadow Sampling Grid



ARCHAEOLOGICAL BACKGROUND: Surveys in Kirkdale South Meadow revealed no surface features on the lower flood plain, but above the scarp, close to the churchyard wall, there is an earthwork suggestive of a small building. Further south, a low bank extends eastwards from the lane hedge, curves around to the south (running parallel with the scarp) and ends by a shallow ditch (see Figure 4.31). In 1998, a trench was excavated across this bank. The limited amount of evidence it revealed suggested a medieval origin (Rahtz, pers. com.).

Figure 4.31 Kirkdale South Meadow (Rahtz, pers. com.)

Soil was taken from the field on a twenty metre grid (see Figure 4.30)

Kirkdale North Meadow

SITE DETAILS: Kirkdale North Meadow is a long narrow field (1.3 ha) running north west from the north wall of the churchyard and bound on the east and north by Hodge Beck (see Figure 4.32) On the western side, the meadow gives way to the steep wooded side of the dale. The meadow lies almost entirely below the 50m contour and is, for the most part, level and supports well preserved ridge and furrow. The soils are of variable depth (up to 1.5 m) and consist of a mixture of alluvial or colluvial deposits which are more neutral (pH 6.3) than those of the meadow south of the Minster.

Figure 4.32 Kirkdale North Meadow (Rahtz, pers. com.)

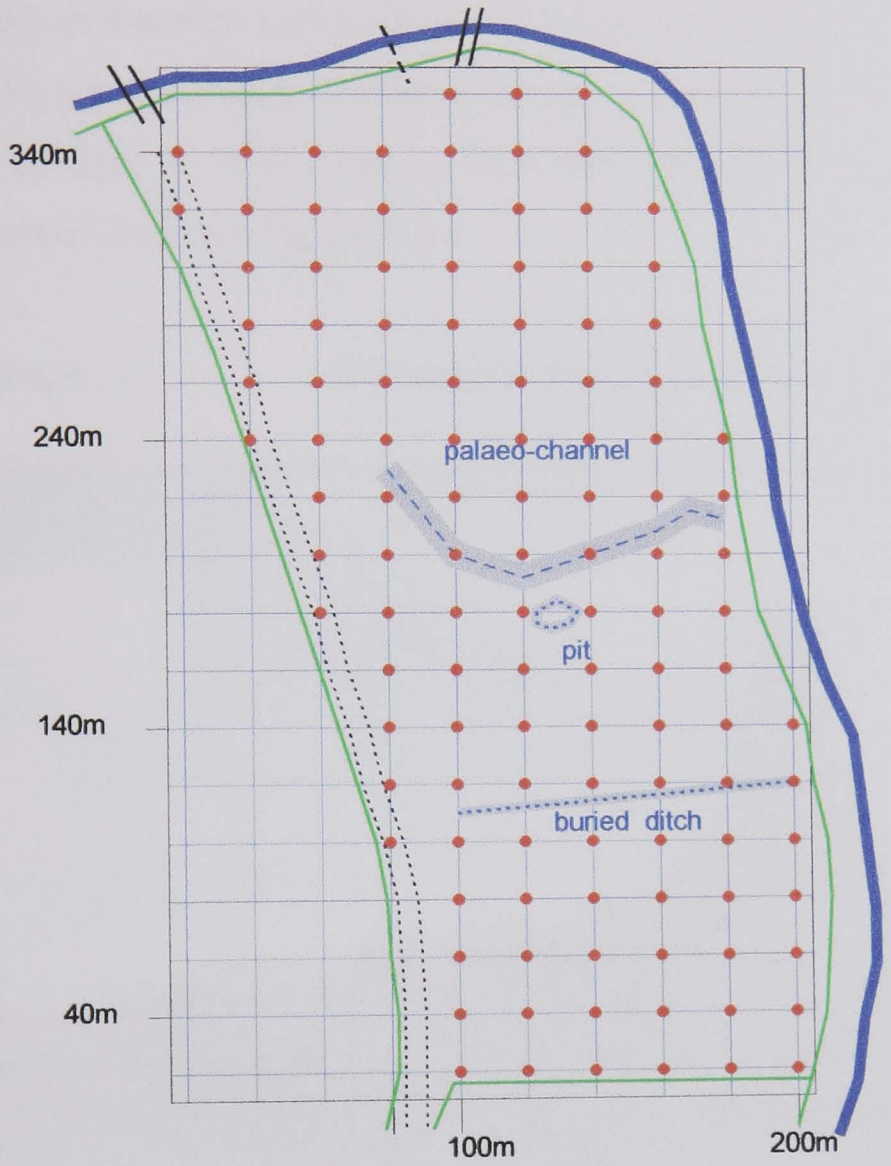
ARCHAEOLOGICAL BACKGROUND: The only obvious archaeological feature of Kirkdale North Meadow is the well preserved ridge and furrow system that runs along most of the long axis of the field. During 1995, a partial geophysical study (gradiometry)

revealed several aligned linear features fifty metres north of and parallel with the churchyard wall. Further Gradiometry (see Figure 4.33) and follow up excavations (subsequent to the soil analysis survey) revealed further linear anomalies in the southern half of the field, rectilinear patches (4 or 5 m across) in the same area and, what appeared to be, an old palaeo-channel dividing the field somewhat sinuously. Excavation revealed one of the patches to be 13th Century clay pit partly filed in and covered with medieval industrial debris including burnt clay, ferrous slag and scrap lead melt. The palaeo-channel proved to be the edge of a pre-13th century (but not pre-Roman) wash-out which may have removed the top half of the field down to a depth of 2.5 m. The remaining features have yet to be investigated.

Figure 4.33 Gradiometry Survey of Kirkdale North Meadow
(vertical scale –1 sd white & +1 sd black) - Rahtz, 1997

Soil was taken from the field on a twenty metre grid (see Figure 4.34)

Figure 4.34 Kirkdale North Meadow Sampling Grid



SITE TWELVE

Kinaleghin Priory

SITE DETAILS:

The site comprises of two fields and a paddock lying in low undulating grassland (50m - 60m above mean sea level) and set around (but largely to the north of) extant farm buildings at Abbey in Galway, Republic of Ireland (see Plate 4.13). Approximately 3.5 ha of highly variable soils(e.g. from peat-rich soils to silty clay loams …pH 4.9 – 7.4) was sampled (see Figure 4.35).

Plate 4.13 **Kinaleghin Priory (remains of old church).**

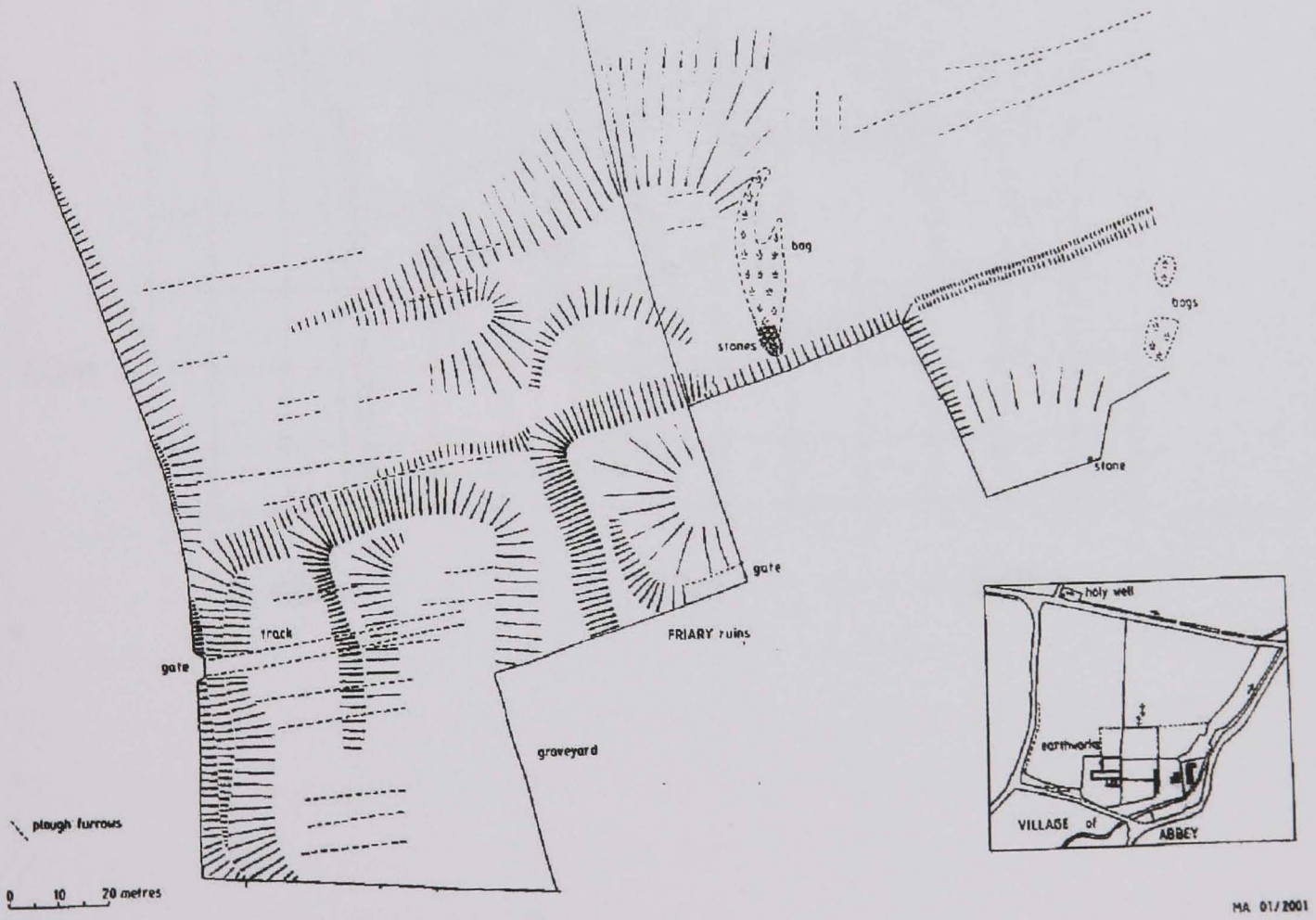
Photo M. A. Aston

ARCHAEOLOGICAL BACKGROUND:

The Carthusians, a purely contemplative order of individual monks (hermits), originated in France in the late 11th Century. Their settlements are unique in being simple assemblages of cells (self-sufficient units with a garden attached) around a central cloister. A church provided a place for communal worship when that was appropriate. The priory at Kinaleghin was founded in 1252 and abandoned only 90 years later (1341?). It was eventually taken over and developed by the Franciscans in 1391 who occupied the site until the Dissolution. Nothing remains above ground of the 13th Century settlement but documentary evidence, surviving alignments, earthworks and

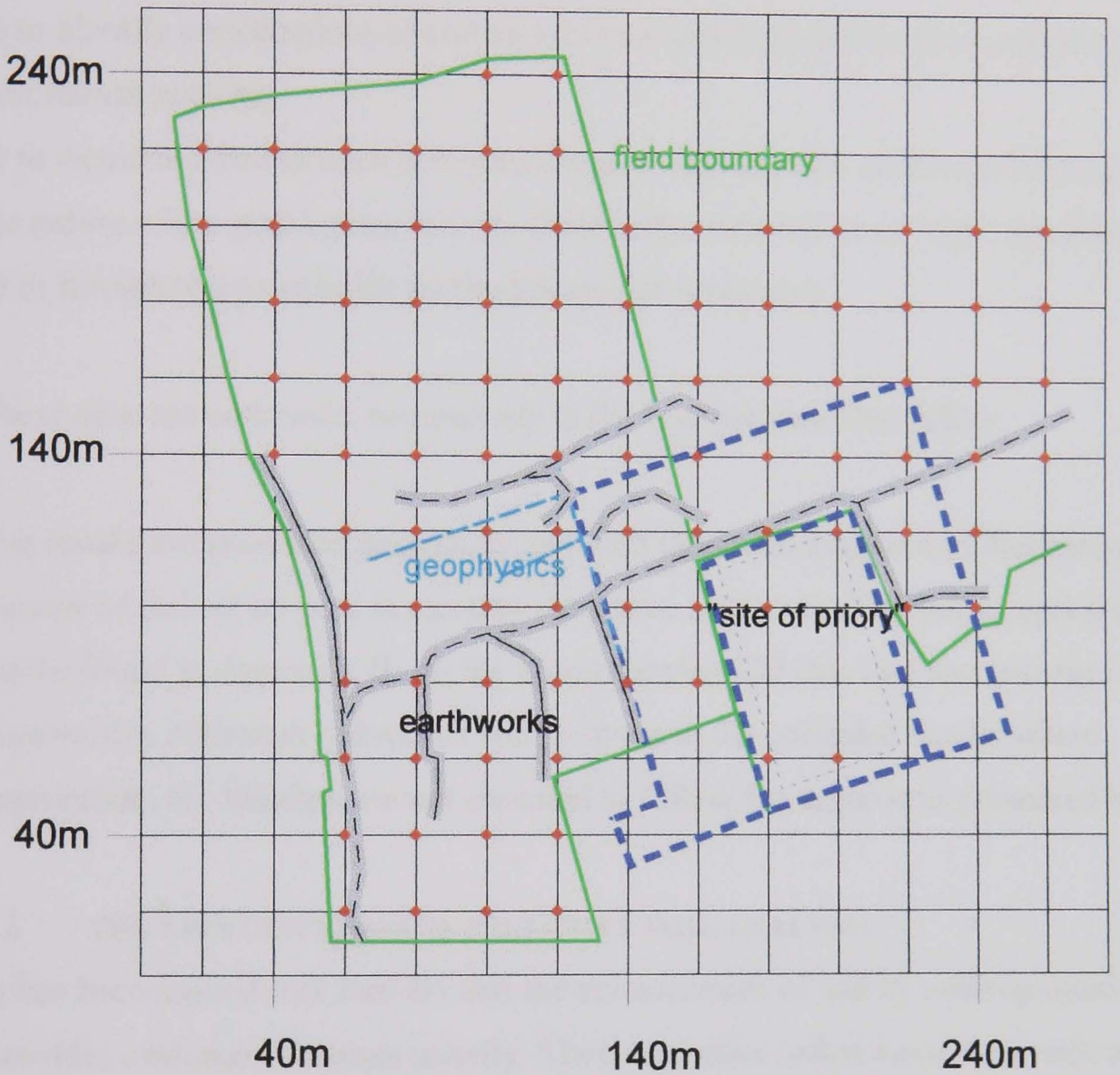
recent geophysical data would indicate that the cloister lay under the small paddock. It is conjectured that the hermit cells (with their rear gardens) faced on to this paddock and that the church lay beyond the south west corner. This church was probably re-used by the Franciscans which is why it still survives as part of the existing farm buildings (Aston, pers. com.). The site has been subject to archaeological investigation by the University of Bristol and an earthwork survey is presented below (see Figure 4.35).

Figure 4.35 **Kinaleghin Priory Earthwork Survey**



The area under investigation was soil sampled (see Figure 4.36) and evaluated for phosphorus, heavy metals etc.

Figure 4.36 **Kinaleghin Priory Sampling Grid**



Part Five: Results and Comments

INTRODUCTION

The aims of this dissertation were,

1) to establish whether selected soil-chemical analyses and other soil factors could be used to locate sites of past human activity;

2) to identify combinations of soil factors that consistently provide a correlation with past human activity;

3) to examine whether such soil measurements can provide additional information about the nature of the past human activity (hereinafter referred to as "type signatures): and

4) to formulate a practicable methodology and procedure.

These aims are addressed successively in the four sections that follow.

The results are presented selectively and with the prime intention of illustrating the success or lack of success in meeting the above objectives. The full compiled data set can be found in Appendix II on the accompanying CD disc that accompanies this dissertation. Although references will be made to the compiled results where appropriate, the full data are not essential to follow the arguments presented below.

5.1 THE EFFECTIVENESS OF SELECTIVE SOIL ANALYSIS

It has been argued (see Part II) that the enhancement of soil by anthropogenic residues provides evidence of human activity. These activities (often associated with a settlement) have generated enriched soils that are co-incident with the archaeology. However, enhancements that cannot be clearly associated with earthworks, excavated features, or geophysical plots may, nonetheless, be of human origin. The interpretation of soil analytical data is often limited by the absence of corroborative archaeological evidence but can only improve with the cumulative results of further investigations. At this stage, what may appear to be a poor fit with the archaeology, cannot be necessarily dismissed.

5.1.1 Individual Factors

A. PHOSPHORUS

The longest established and most proven archaeological soil analytical technique is phosphorus evaluation (see Part 2, page 85). How has this performed on the sites examined? How do the analyses for magnetic susceptibility, organic carbon (loss on ignition), soil pH and heavy metals compare with those for phosphorus ?

The evaluations (Table 5.1) show a wide range of soil phosphorus concentrations (159 mg / kg to 7835 mg / kg). (*Please note that all soil chemical concentrations given in this and the following sections are for soils oven-dried at 80°C).*

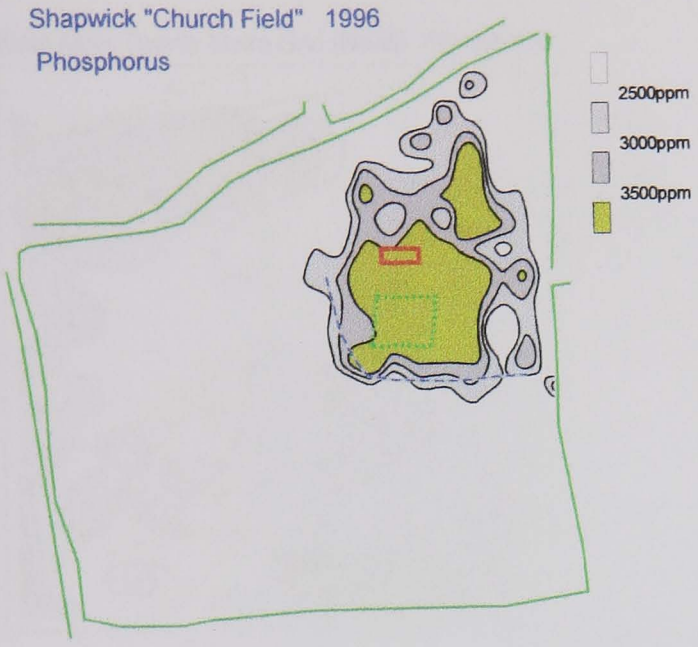
Table 5.1 Phosphorus evaluation – recorded values. Some of the 12 sites / 19 evaluations have been amalgamated for simplicity sake on the basis of proximity and similarity in soil type.

Evaluation	Phosphorus mg / kg (or ppm)		
	Mean	Range	
		minimum	maximum
Shapwick (3 sites, 4 evaluations)	2127	655	5458
Hamm Farm (7 sites/evaluations)	1452	780	3881
Puxton (2 sites)	2013	917	3984
Vole Farm	1970	1236	5195
Lower Woods	3018	159	6214
Blackcliff Woods	1832	836	5729
Kirkdale (2 sites)	1628	625	3408
Kinaleghin Priory	2620	822	7835
Overall mean & range	1871	159	7835

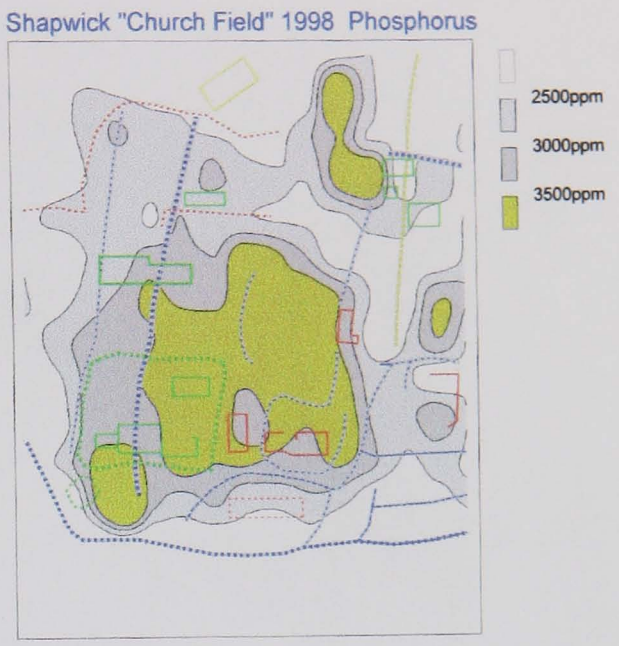
Bearing in mind that all sites were chosen because they either exhibited evidence of human activity or that such activity was suspected, it is unlikely that the amount of phosphorus, or indeed of any humanly generated soil factor, would not have been enhanced or altered in some way. At Hamm Farm (the 50m survey, which is not individually illustrated above) the peak elevation of soil phosphorus was four times the mean concentration (maximum 5357 mg/kg; mean 1357 mg/kg).

Figure 5.1 (Continued) Phosphorus Isoline Maps

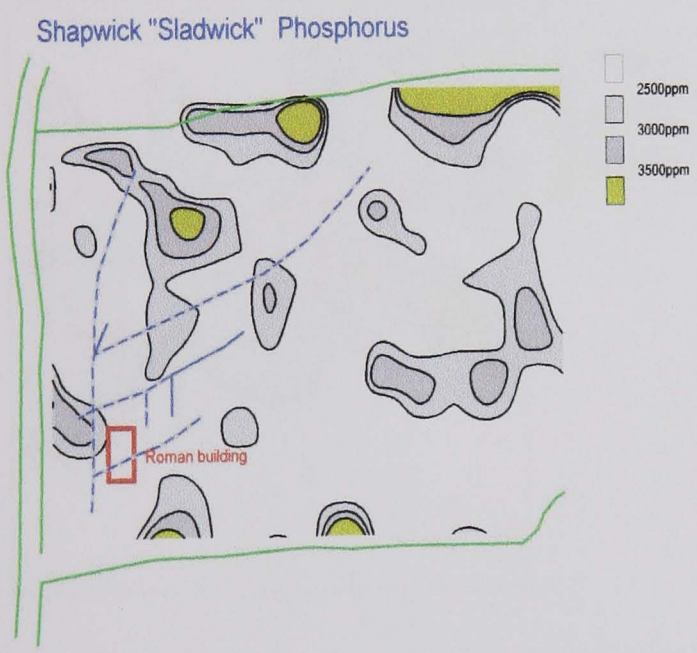
A. Site 1a (page 135)



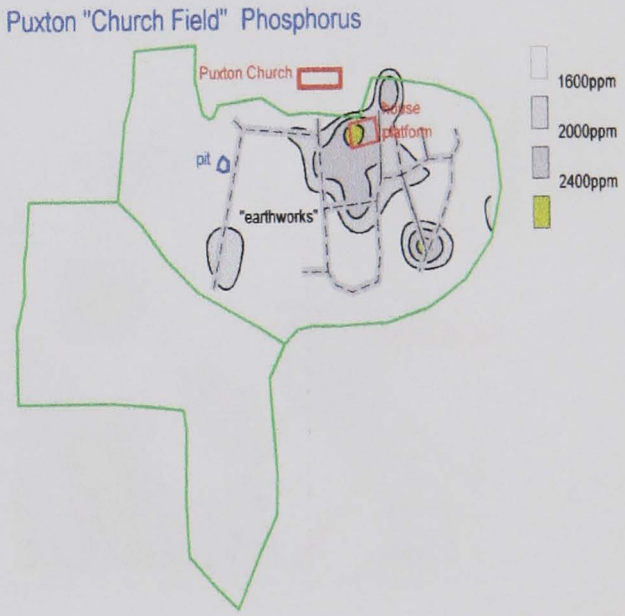
B. Site 1b (page 135)



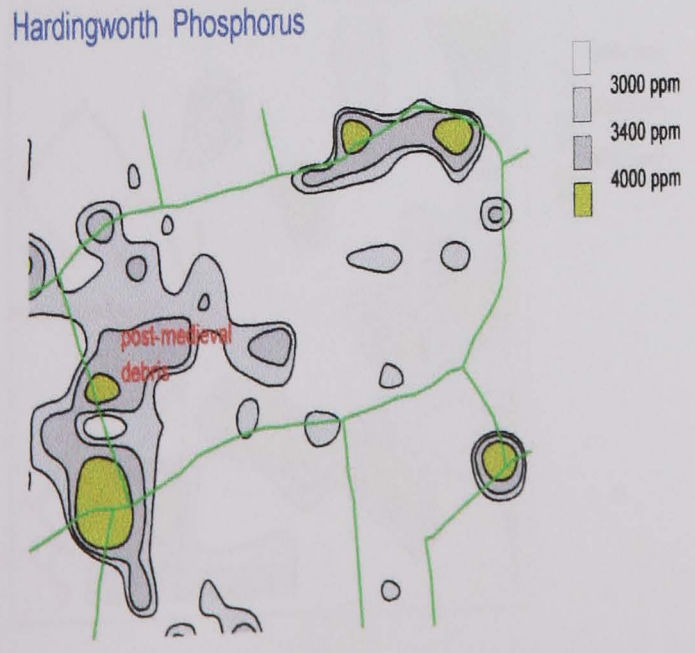
C. Site 3 (page 145)



D. Site 5 (page 156)



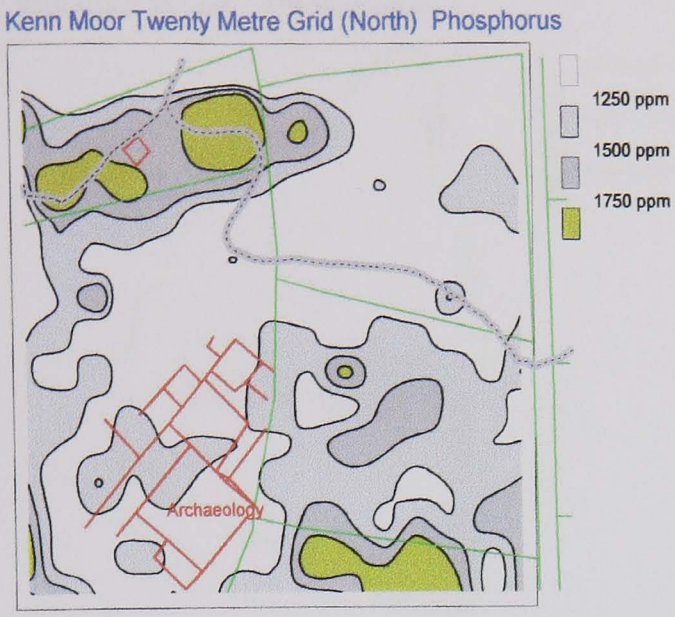
E. Site 7 (page 163)



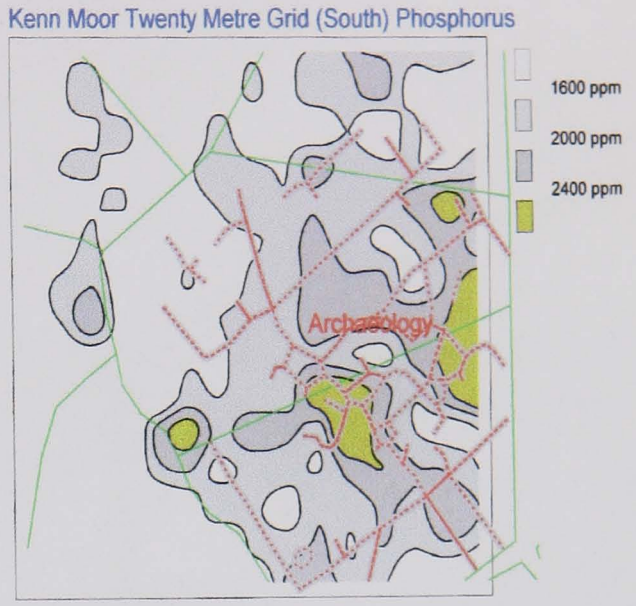
F. Site 4 (page 152)

Figure 5.1 (Continued) Phosphorus Isoline Maps

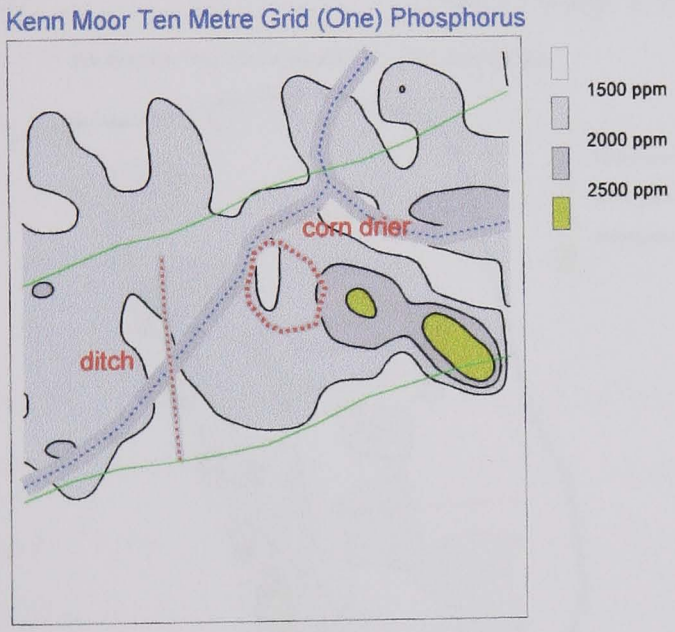
G. Site 4 (page 152)



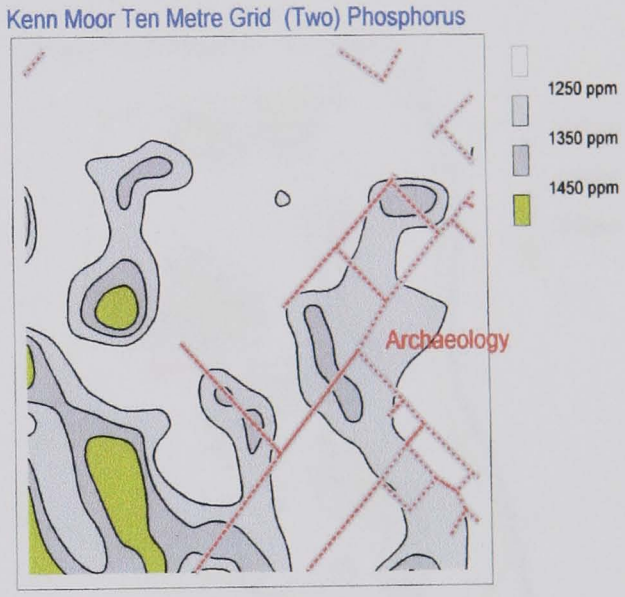
H. Site 4 (page 152)



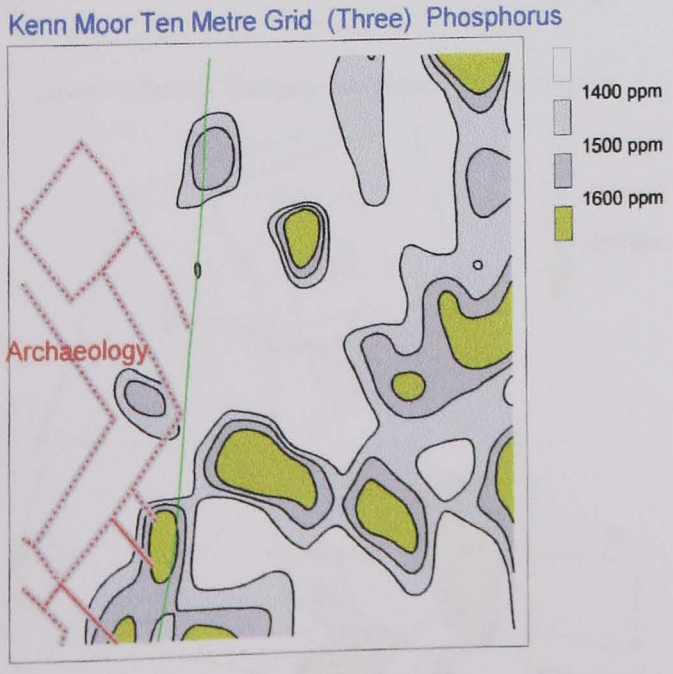
I. Site 4 (page 152)



J. Site 4 (page 152)



K. Site 4 (page 152)



L. Site 4 (page 152)

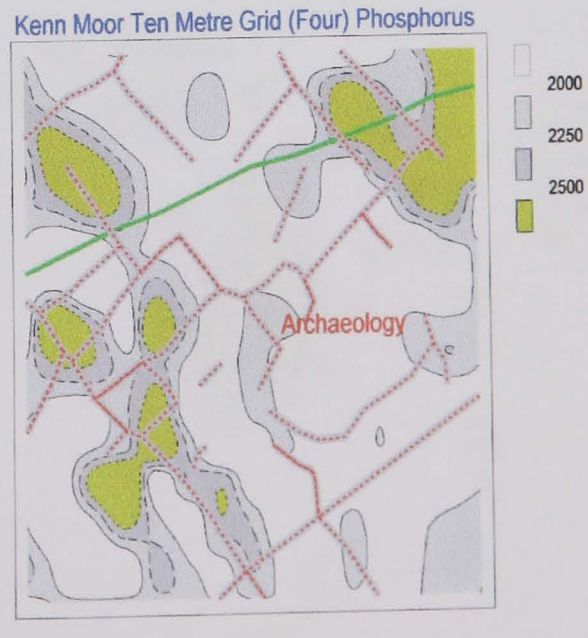
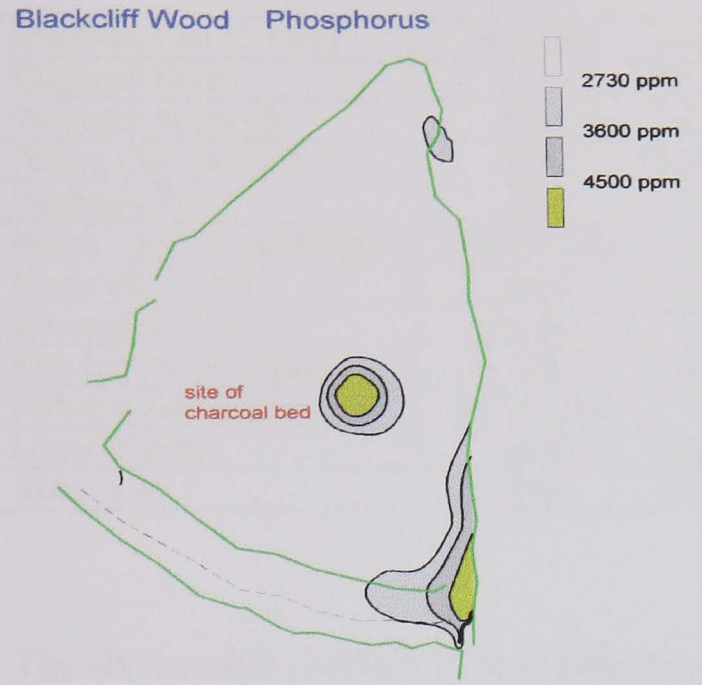
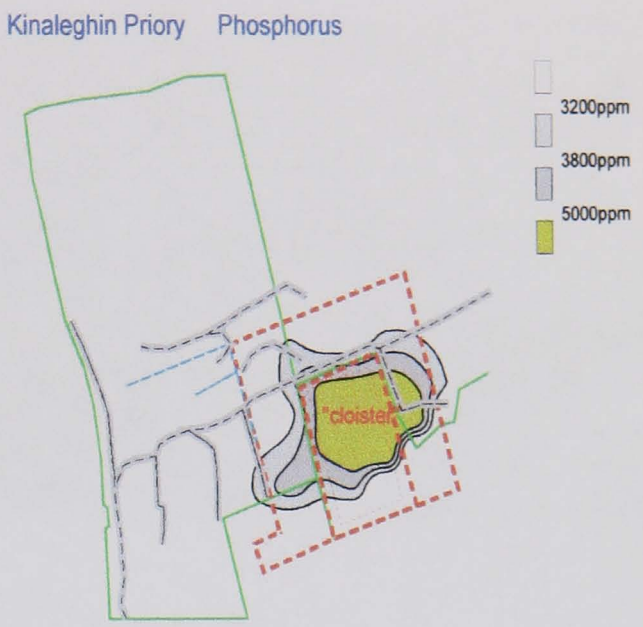


Figure 5.1 (Continued) Phosphorus Isoline Maps

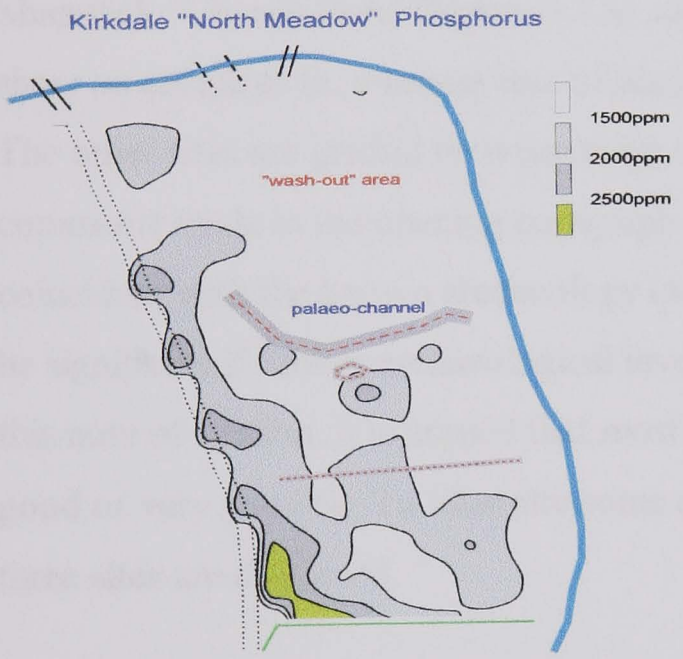
M. Site 9 (page 169)



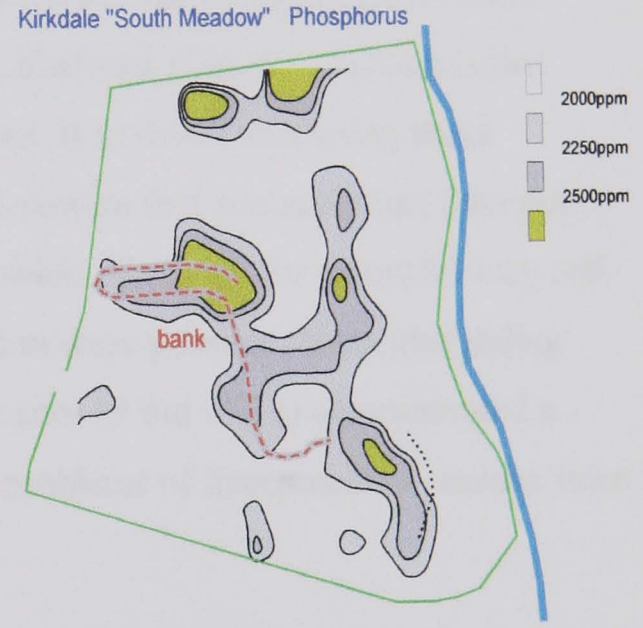
N. Site 12 (page 178)



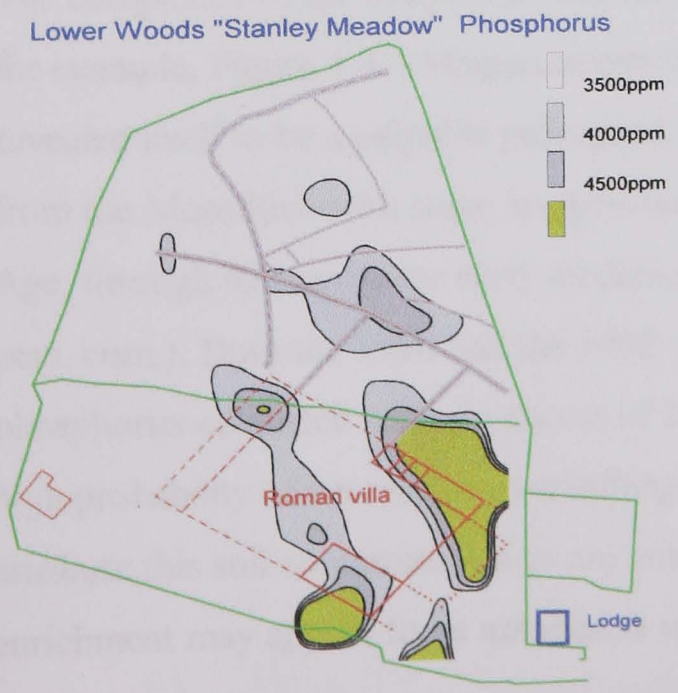
O. Site 11 (page 175)



P. Site 10 (page 173)



Q. Site 8 (page 165)



R. Site 6 (page 160)

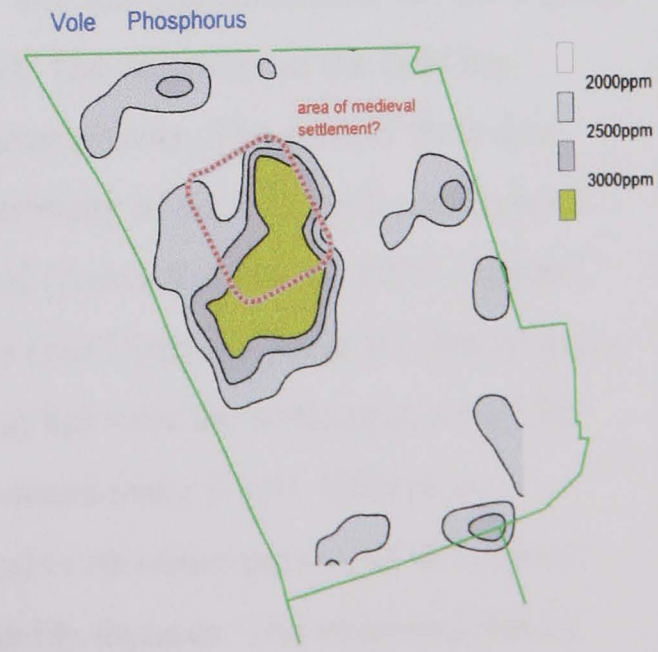


Table 5.2 Phosphorus evaluation - co-incidence with known human activity

Site	Phosphorus ("fit")	Comment
Shapwick Church Field	very good	contained within the settlement boundary
Shapwick Henry	fair ?	possibly consistent with recent farm practices (Fig 5.2B)
Shapwick Sladwick	poor	no clear tie with the archaeology as it is known
Puxton Church Field	good	clearly coincident with earthworks
Hardingworth	good	some co-incidence with post-medieval debris
Hamm Farm (Kenn Moor)	poor to good	some evaluations consistent with settlement
Blackcliff Woods	good	coincident with charcoal bed
Kinaleghin Priory	very good	coincident with cloister area (or modern cattle paddock)
Kirkdale North Meadow	fair	generally co-incident with suspected settlement area
Kirkdale South Meadow	fair to good	co-incident with suspected settlement area
Lower Woods	good	coincident with Roman buildings
Vole Farm	good	clearly coincident with earthworks

The above table (Table 5.2) is a subjective evaluation based on coincidence of the higher concentrations of soil phosphorus with the known archaeology. The surveys of Shapwick "Church Field"(Figure 5.1A) and Kinaleghin Priory (Figure 5.1N) both show an excellent fit, whereas that of Shapwick, Sladwick (Figure 5.1C) was poor. The other sites are graded between these extremes. It is worth reiterating those comments made in the opening paragraph of this section that soil analytical data not coincident with the known archaeology (at Shapwick, Sladwick for example) may still be significant if further archaeological investigation were possible. Notwithstanding this note of caution, it is argued that most of the sites (9 out of 12) demonstrated a good or very good fit. To illustrate some of the problems of interpretation, results from three sites are discussed.

Too much archaeology:

The complexity of the Shapwick "Church Field" site has been described in Part 4 (See, for example, Figure 4.4 – Magnetometry Survey). The northeast of the field has revealed itself to be a palpable palimpsest of human activity. The earliest finds date from the Mesolithic with some suggestion of continuity of occupation from the Iron Age, through Roman to the early medieval period (Aston & Gerrard, 1995; Gerrard, pers. com.). Both the 1996 and the 1998 surveys (see Figures 5.1A & B) clearly show phosphorus-enhanced soils (in excess of 2500 mg/kg) over the settlement area. The high probability of successive overlapping settlements make it very difficult to attribute this soil contamination to any one period even where peaks and troughs of enrichment may appear to be associated with datable features. The interpretation of

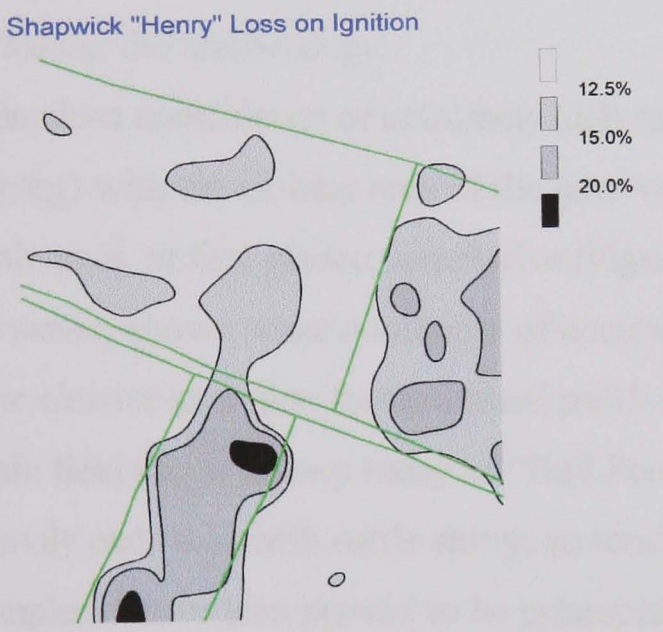
multi-period sites remains problematical when considering the analytical results of a single soil factor.

Too little archaeology:

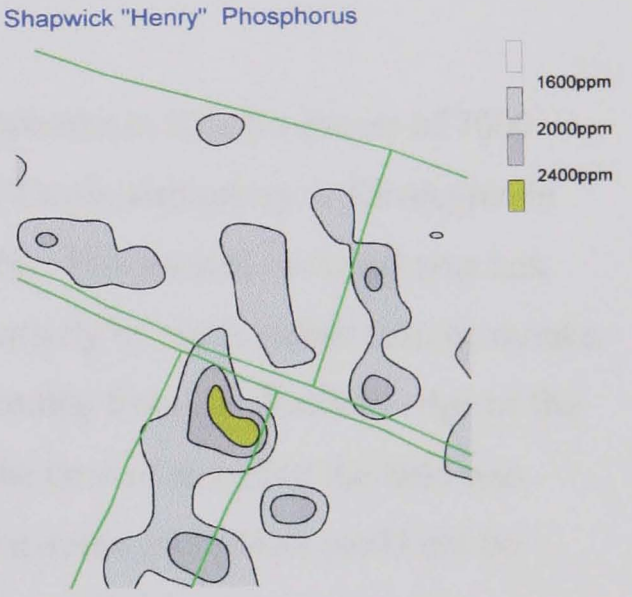
The soil analytical data from Henry, on the other hand, showed some promise but had little supporting archaeological evidence (see Table 5.2 & Figure 5.2 B). Field names suggesting the possible proximity of an early Saxon homestead, some partial and inconclusive geophysics (see Part 4 & Figure 4.8) and a little fieldwalking were all there was to go on. Soil analysis revealed some patches of high phosphorus (in excess of 2400 mg/kg) in a small paddock to the south of the farm track and in a meadow adjacent to the present Manor farm (see Figures 5.2 A & C – Manor Farm, which is not shown, lies just to the right of the survey area). The phosphorus counts were matched by elevations in soil

Figure 5.2 **Evidence of human activity in "Henry"**

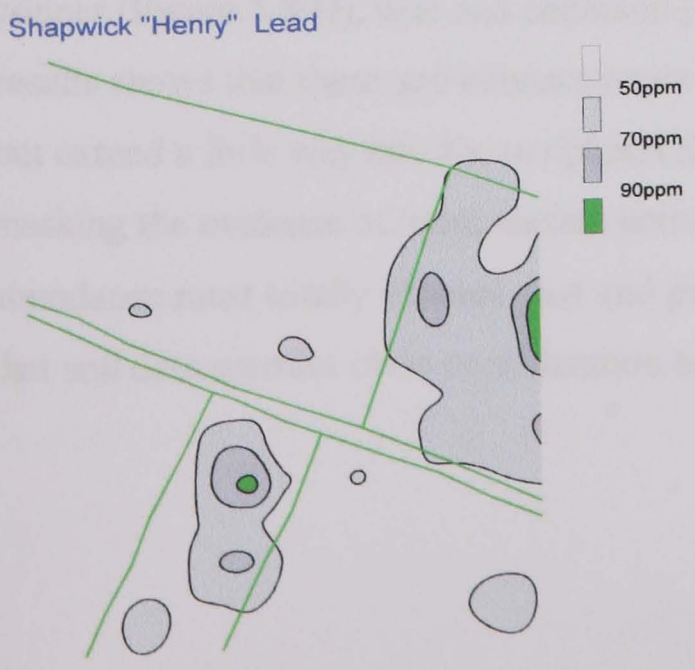
A. Site 2 (page 142)



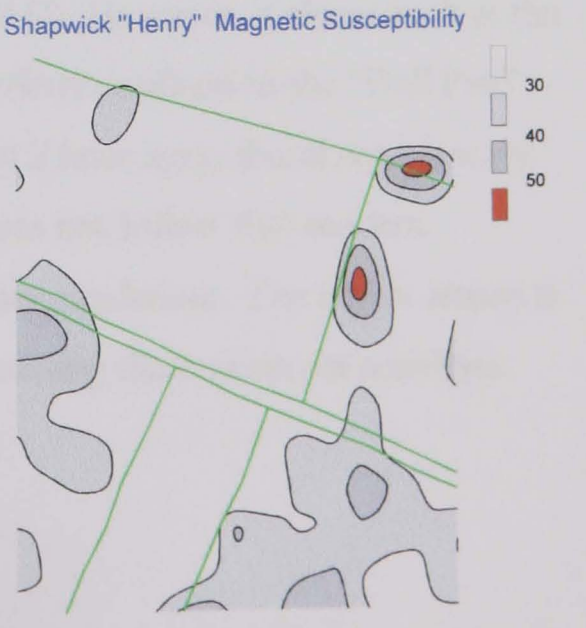
B. Site 2 (page 142)



C. Site 2 (page 142)



D. Site 2 (page 142)



matched by elevations in soil organic carbon (loss on ignition) and lead. The other peculiarity were two patches of enhanced magnetic susceptibility in the meadow (see Figure 5.2 D). An early medieval origin of these soil enhancements cannot be ruled out, but there is another plausible interpretation. On consulting past editions of Ordnance Survey maps it was evident that both the paddock and the meadow had been orchard up until the recent past (post 1939 – 1944 War period). It was common practice in this part of Somerset to graze sheep in orchards. Accumulations of sheep dung, leaf and apple fall could easily account for increases in soil phosphorus, organic matter and lead. Lead-based pesticides were also widely used on fruit trees, even into the post-War period and this alone could account for high soil-lead levels. These orchards were eventually grubbed and the trees stacked and burned. The magnetic susceptibility readings in the meadow next to the farm could well be the site of these bonfires (see comments on the Boy Scout's bonfire and the charcoal bed in the Magnetic Susceptibility section below.). This scenario is speculative, but illustrates how relatively recent activities might be misinterpreted as past events.

Masking the archaeology:

The close coincidence of extremely high soil phosphorus counts (in excess of 7000 mg/kg) with the cloister area of the now vanished Carthusian priory at Kinaleghin in Galway is, at first glance, impressive (Figure 5.1 N). This ancient enclosed area has, however, shown some continuity of occupation, latterly by cattle rather than by monks. The cloister area now forms a small paddock extending from the northern edge of the main field and is known today as "Bull Pen". At the time of sampling the field was heavily endowed with cattle slurry, so much so that some grid points could not be sampled. There also proved to be enhancements in the cloister area of magnetic susceptibility (Figure 5.3 N), organic carbon (Figure 5.4 N) and the heavy metals copper (Figure 5.8 D), zinc and cadmium (Figure 5.7 C). However, a closer look at the results shows that these soil enhancements are not strictly confined to the "Bull Pen" but extend a little way into the peripheral fields. Even if later agricultural practices are masking the evidence of more ancient activities, it does not follow that modern abundance must totally obscure past and prolonged accumulations. The object lesson is that soil data warrant close consideration before dismissing them as recent activities.

Magnetic Susceptibility

Magnetic susceptibility ranked third in those soil factors best indicative of human activity (see Table 5.3) and clearly identified the Carthusian cloister in Galway, the Roman villa in Lower Woods and the (probable) medieval settlement at Vole (see Figures 5.3 N, Q, & R). The results were less clear on Hamm Farm near Kenn Moor where a field that lay between the two major zones of past human occupation gave far and away the highest readings (see Figures 5.3 F, H, & K). The field in question was across the road from an intensive livestock unit and may, over recent years, have received disproportionate amounts of animal slurry. Unfortunately, this explanation is not borne out by similar elevations in other effluent-associated soil factors (loss on ignition, phosphorus, lead etc) so the reason for the anomalous readings remains unknown. Certain other features of the results from laboratory assessments of magnetic susceptibility are worth comment.

Recently burned material;

Soil analysis of the meadow north of St Gregory's Minster at Kirkdale largely bears out the archaeological evidence of early medieval flood-erosion (see Figure 5.3 O). Certainly the half of the field beyond the buried palaeo-channel (see Figure 4.30) appears relatively un-enriched. The notable exception is a patch of magnetically enhanced soil co-incident with the site of the annual Boy Scout's bonfire. A similar "hot spot" was evident within the Dark Age enclosure in Blackcliff Woods (see Figure 5.3 M). Here the larger enhancement was associated with a surface spread of charcoal fragments (see Part 4) and elevated readings of phosphorus, organic carbon and lead (see Figures 5.1 M, 5.4 M, 5.6 M). At Hardingworth in north Somerset, high magnetic susceptibility readings ran the length of a ditch that had been filled in within the last thirty years possibly with slag or other material that had been subjected to high temperatures (see Figure 5.3 E). Again this was matched by elevated soil levels of lead (see Figure 5.6 E and copper (see Appendix II on the accompanying CD). In this case the infill soils were comparatively alkaline (pH > 7.5) (see Figure 5.5 C).

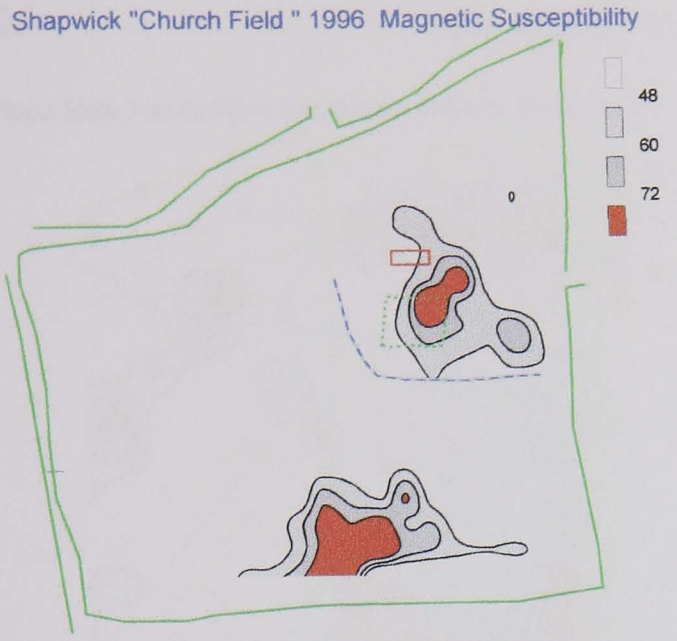
At these three sites soil enhancement by relatively recent activities, a bonfire, a charcoal bed and a recently infilled ditch, have been the dominant feature.

Figure 5.3 shows the isoline maps for magnetic susceptibility distribution for the twelve sites (18 evaluations – see Fig. 5.2 for "Henry") examined

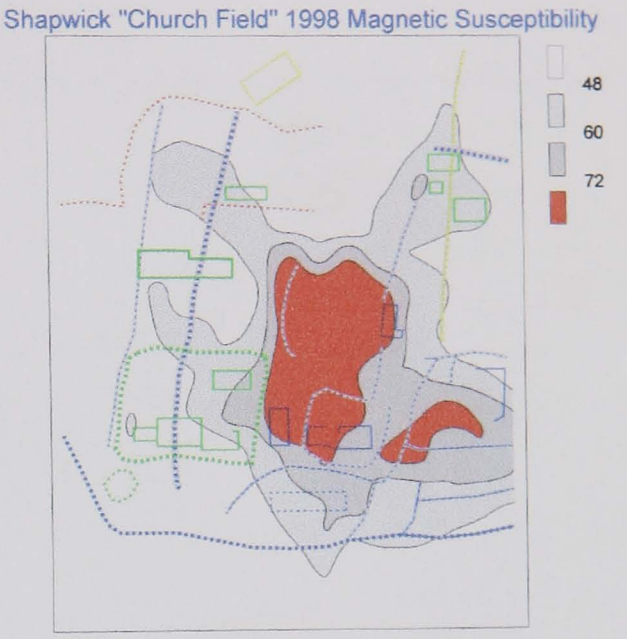
The **vertical scales** on all the magnetic susceptibility isoline maps are based on direct readings from the MS meter, that is on κ values (volume related susceptibility values). These represent the ratio of the field to the magnetisation of the soil and as such are dimensionless (i.e. they do not have units). The recorded values have not, in this thesis, been related to weight or bulk density of the soil. On the opted-for meter setting (the S I scale) the readings are more correctly expressed as $\kappa\ 10^{-5}$. Absolute values are not as important as relative values and the intervals on isoline maps have been set at 1.0 sd (or 0.5 sd for Hardingworth *5.3E*), 2.0 sd and 3 sd above the mean κ value.

Figure 5.3 Magnetic Susceptibility Isoline Maps

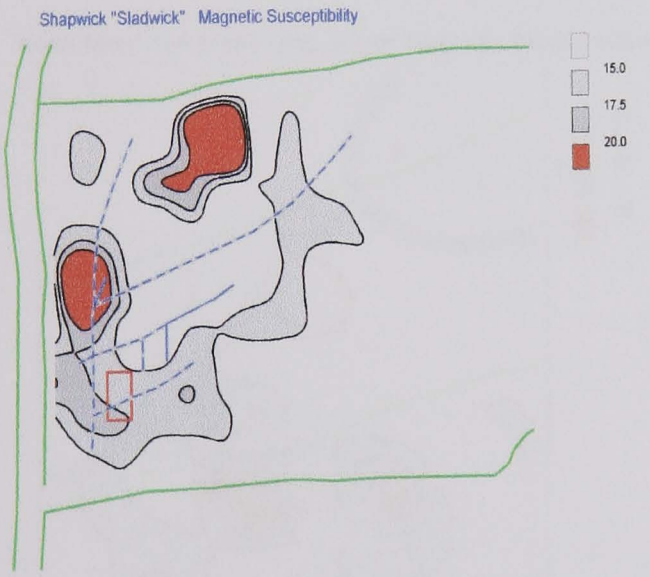
A. Site 1a (page 135)



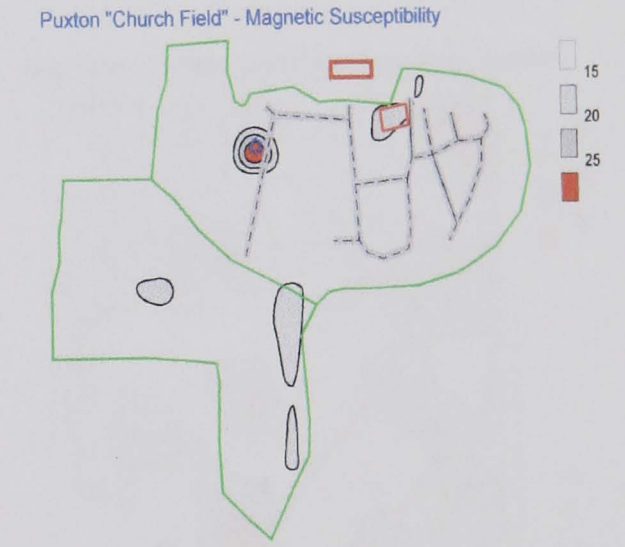
B. Site 1b (page 135)



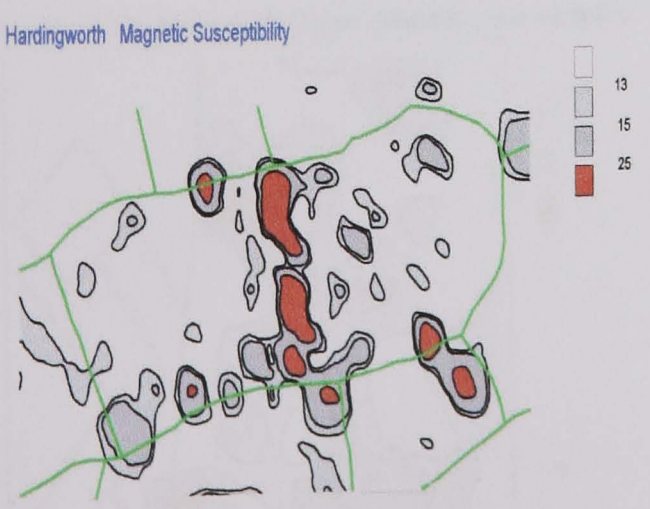
C. Site 3 (page 145)



D. Site 5 (page 156)



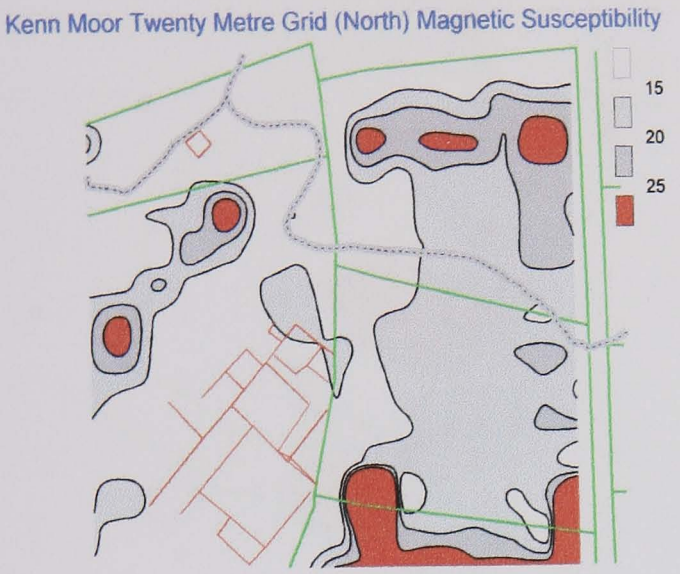
E. Site 7 (page 163)



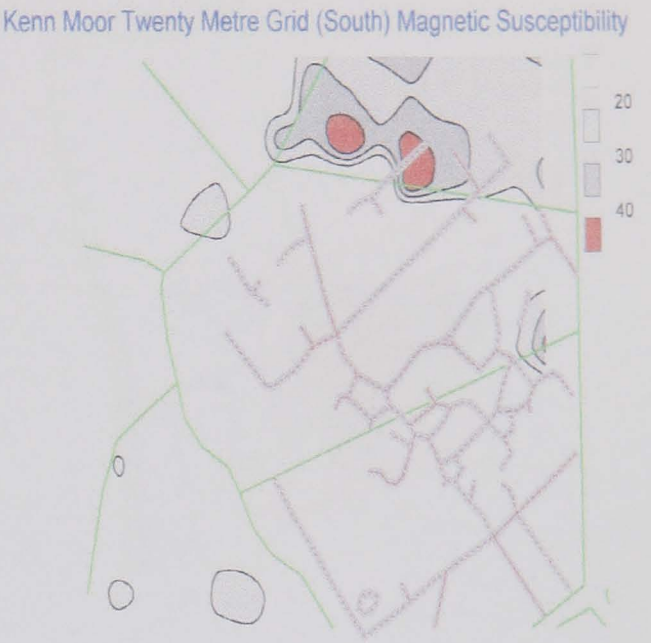
F. Site 4 (page 152)

Figure 5.3 (Continued) Magnetic Susceptibility Isoline Maps

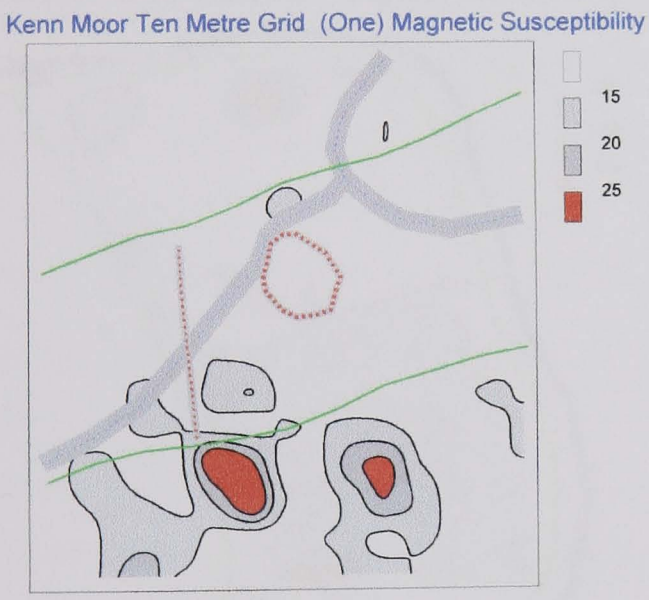
G. Site 4 (page 152)



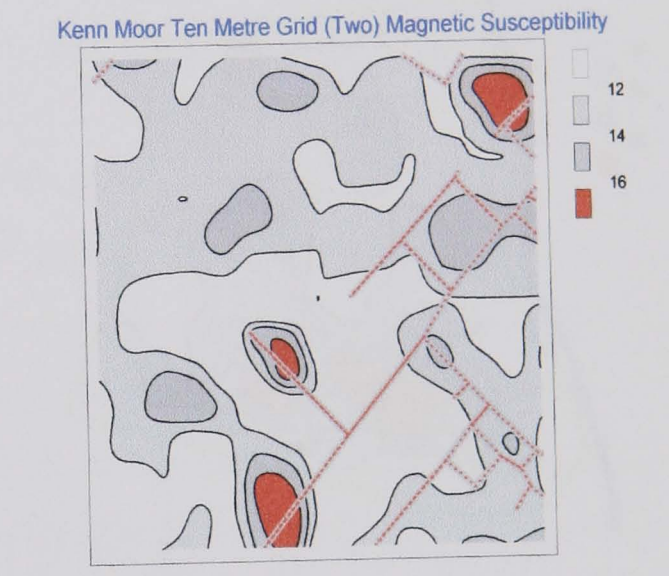
H. Site 4 (page 152)



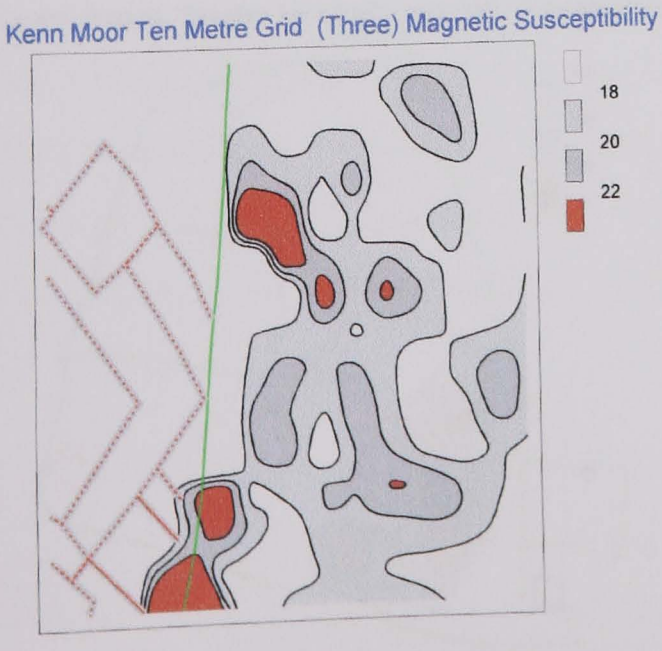
I. Site 4 (page 152)



J. Site 4 (page 152)



K. Site 4 (page 152)



L. Site 4 (page 152)

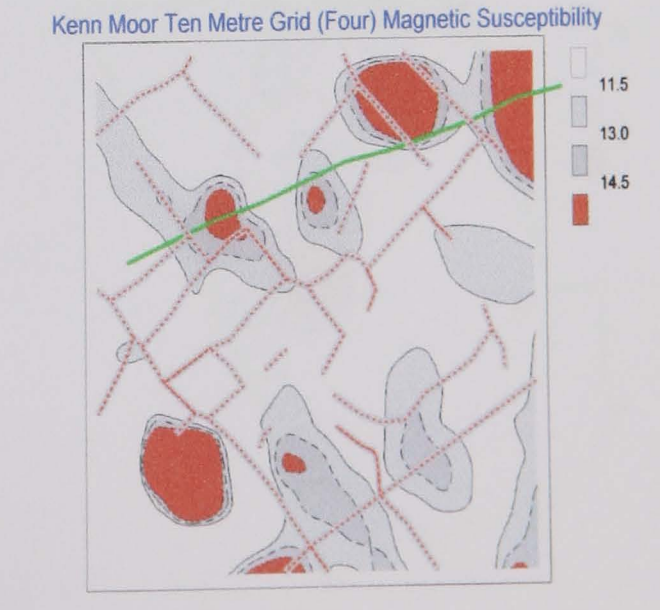
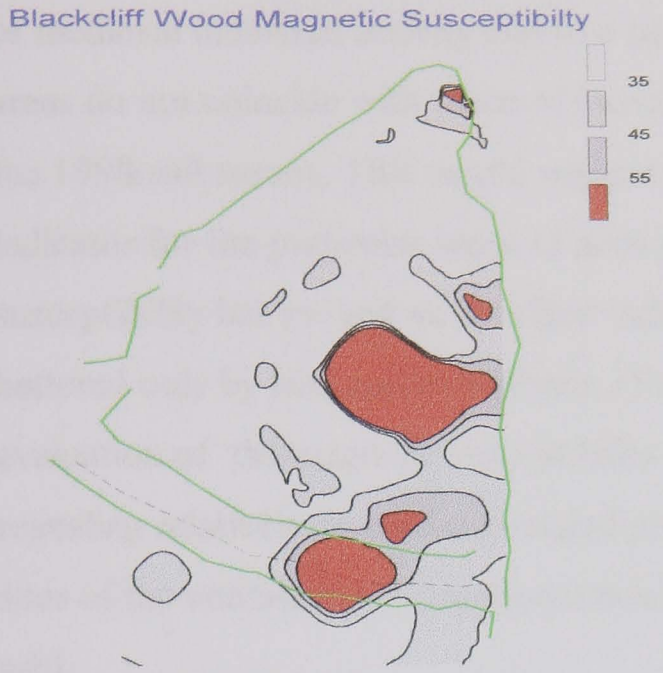
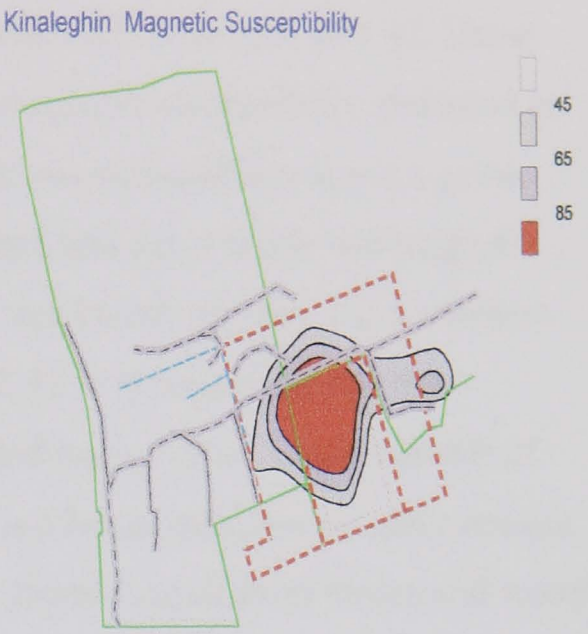


Figure 5.3 (Continued) Magnetic Susceptibility Isoline Maps

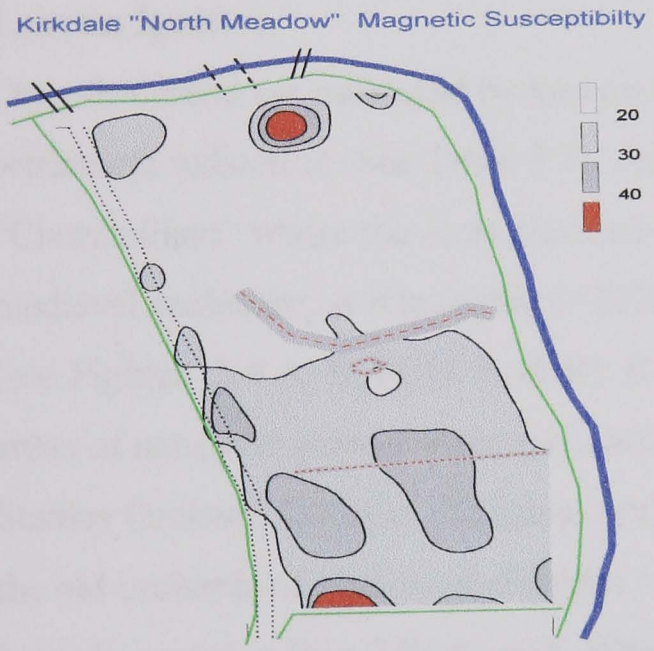
M. Site 9 (page 169)



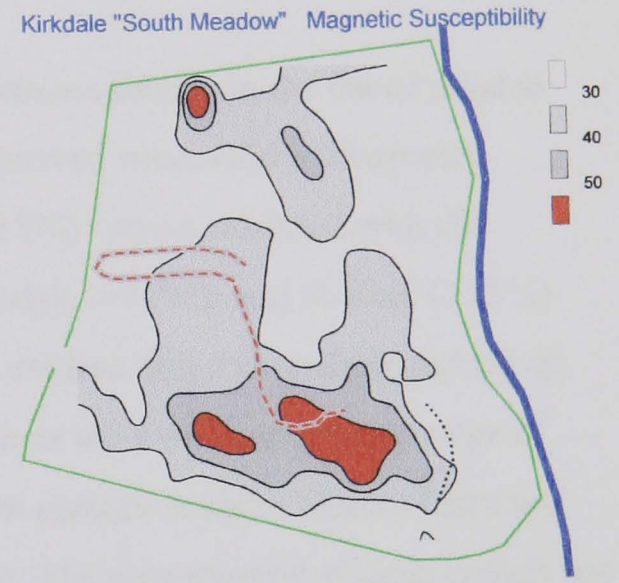
N. Site 12 (page 178)



O. Site 11 (page 175)



P. Site 10 (page 173)



Q. Site 8 (page 165)

R. Site 6 (page 160)

Ancient burned material;

The 1996 magnetometry survey of Shapwick "Church Field" (see Figure 4.4) identified several areas of strongly enhanced magnetism variously ascribed to Roman or medieval industrial activity and to a possible medieval bell pit (see Part 4). These areas do not coincide with those of increased soil magnetic susceptibility identified in the 1998 soil survey. This would suggest that magnetic susceptibility is not a good indicator for the particular types of activity described and yet, overall, soil magnetic susceptibility has proved an excellent indicator of past human activity and settlement bettered only by lead and phosphorus (See Table 5.3). It is suggested that the evaluation of the magnetic susceptibility of air-dried soil samples, whilst capable of revealing relatively recent heat-related processes, is a better indicator on more ancient sites of the cumulative occupational residues (e.g. those derived from faeces and wood ash).

Loss on Ignition

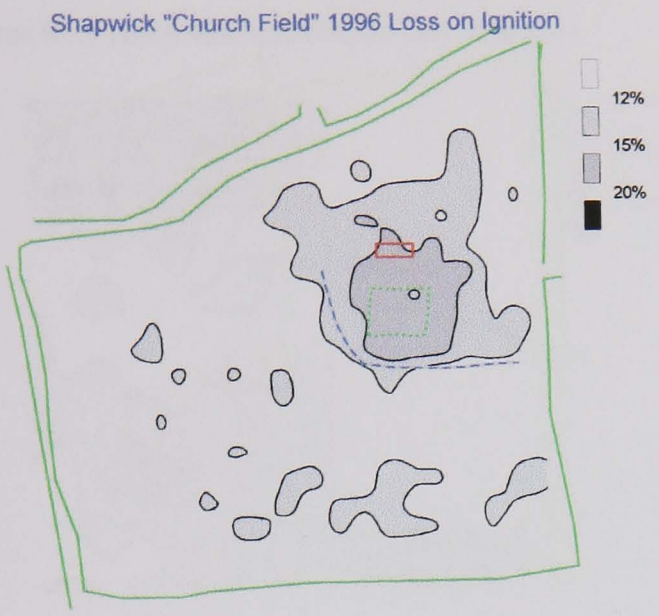
Organic carbon (as measured by loss on ignition) comes fourth on the list of reliable settlement indicators (See Table 5.3). As such, it proved successful in Shapwick "Church Field" where the most elevated levels (>18%) were associated with the medieval enclosure; at Kinaleghin (>20%); at Kirkdale (>11%); and at Vole (>25%) (see Figures 5.4 A, B, N, O, P, & R). It was also evident that soil analysis picked up areas of natural organic-matter accumulation, such as the marshy woodland edge of Stanley Orchard, the dyke dredgings and long term pasture areas of Hamm Farm and the old orchards of Henry (see Figures 5.4 F & Q). The turn-over of organic carbon has been discussed in Part 2 Section D. Whereas most organic matter will oxidise in the short term (days and years), chemically stabilised residues will accumulate over the centuries and persist even longer. In waterlogged soils, the oxidation process is hindered and otherwise vulnerable material will persist. In terms of soil-factor evaluation, there is some parallel here with magnetic susceptibility. Short-term and recent events will sit prominent on the isoline map but so too will the more ancient accumulations of soil-stable anthropogenic residues.

Figure 5.4 shows the isoline maps for organic carbon (as measured by loss on ignition) distribution for the twelve sites (18 evaluations – for "Henry" see Fig. 5.2) examined.

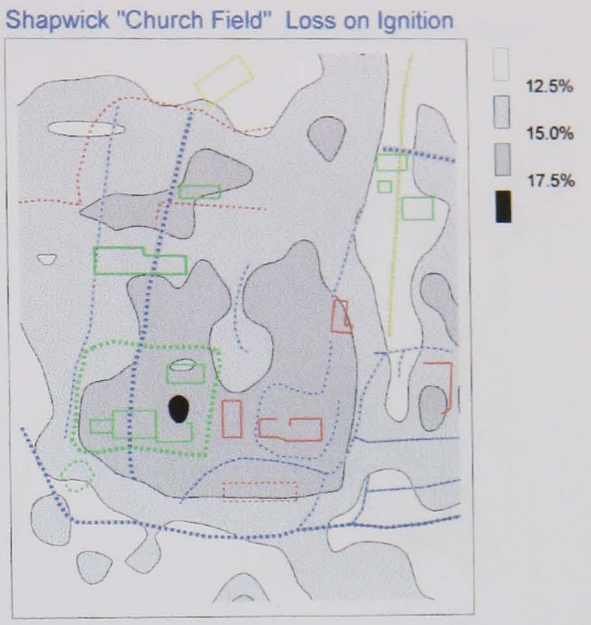
The intervals on isoline maps are set at 1.0 sd (or 0.5 sd for Shapwick "Church Field" 1996 *5.4 A*, Blackcliff Wood *5.4 M* and Vole *5.1 R*), 2.0 sd and 3 sd above the mean

Figure 5.4 Loss on Ignition Isoline Maps

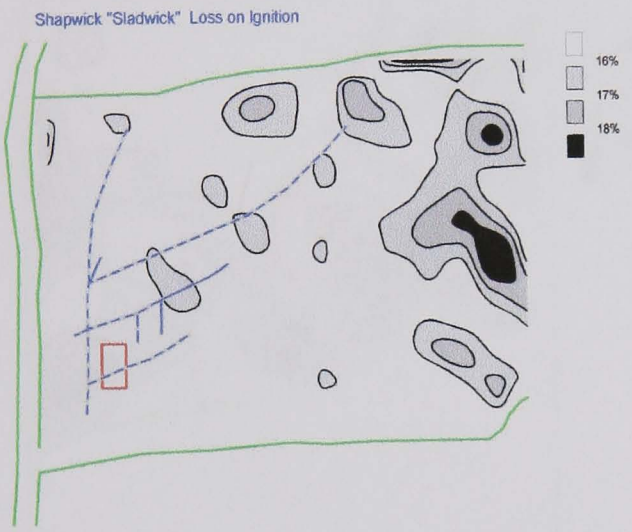
A. Site 1a (page 135)



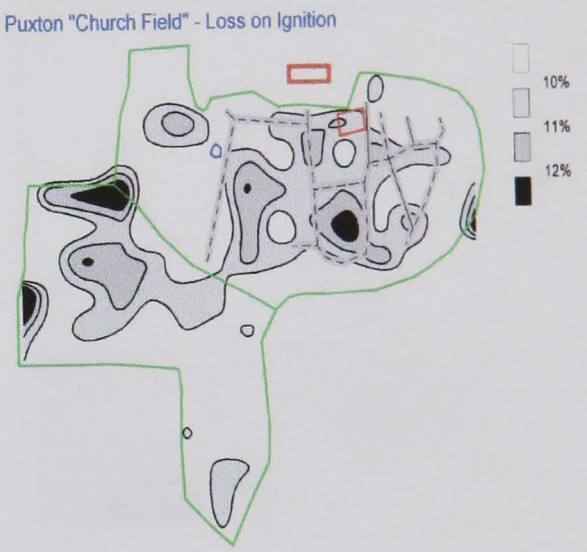
B. Site 1b (page 135)



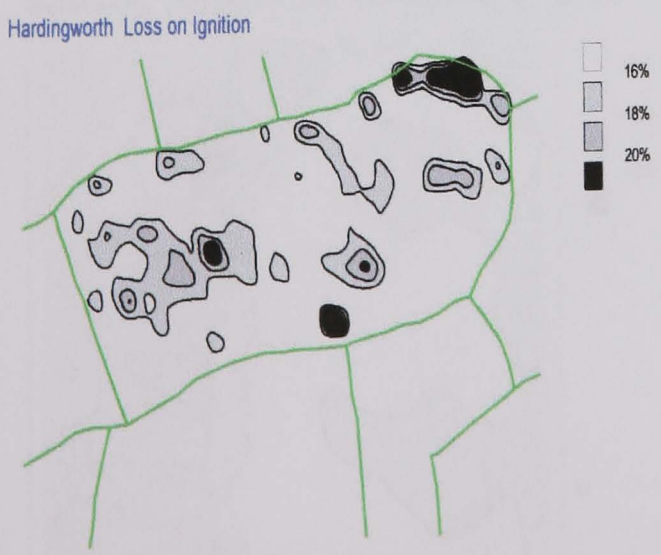
C. Site 3 (page 145)



D. Site 5 (page 156)



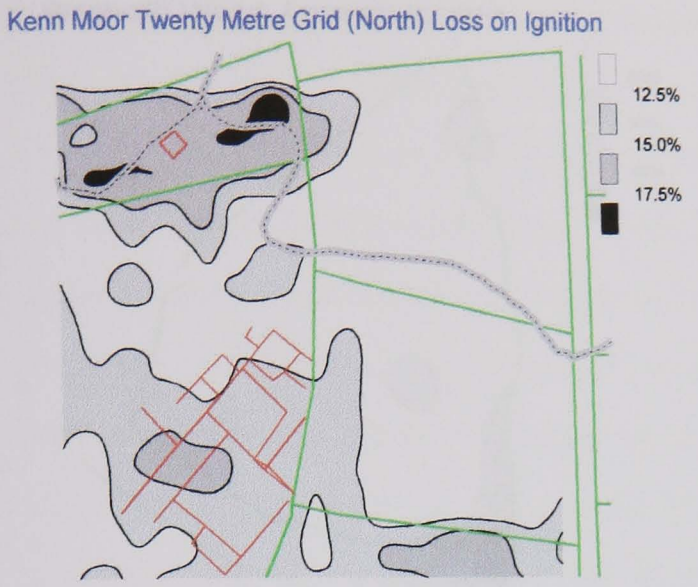
E. Site 7 (page 163)



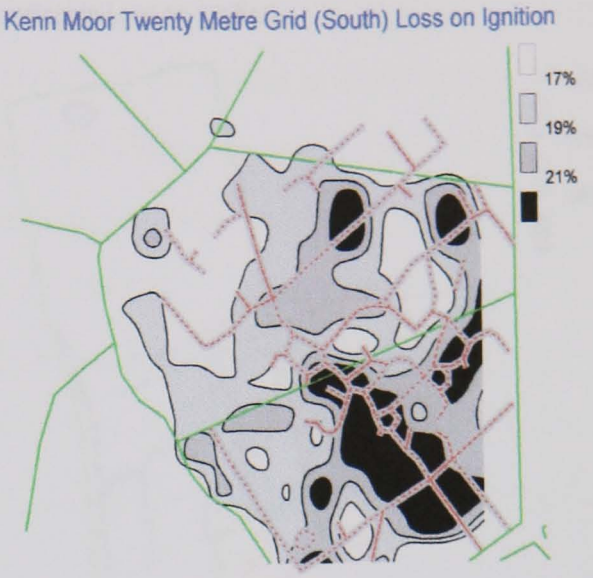
F. Site 4 (page 152)

Figure 5.4 (Continued) Loss on Ignition Isoline Maps

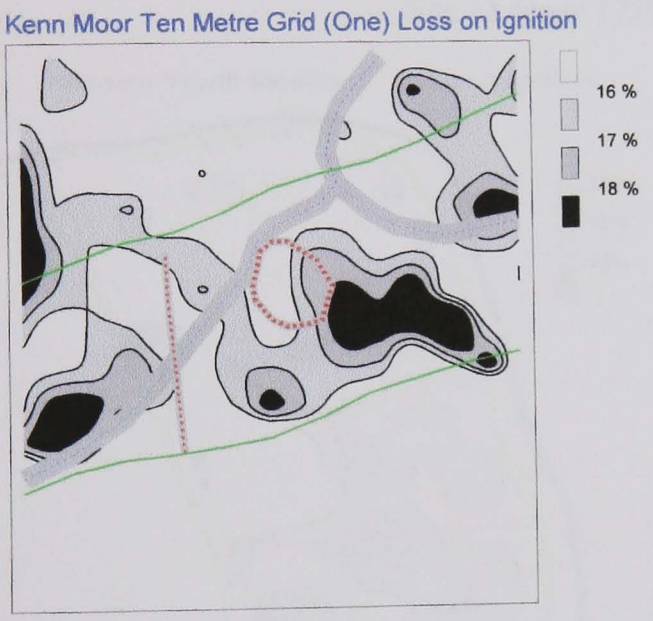
G. Site 4 (page 152)



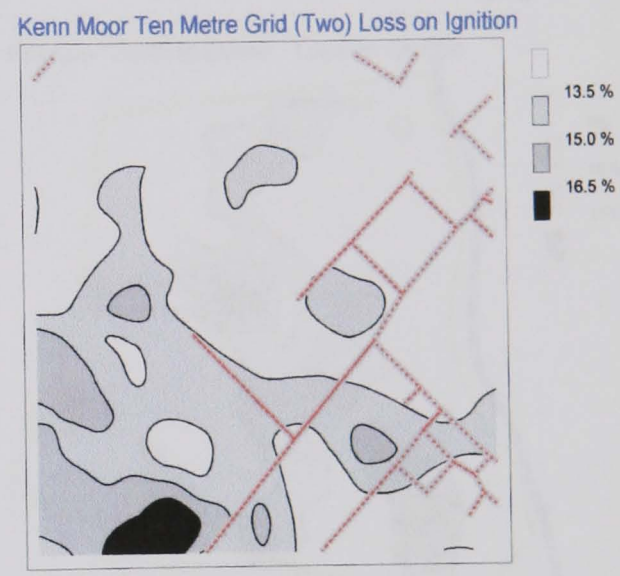
H. Site 4 (page 152)



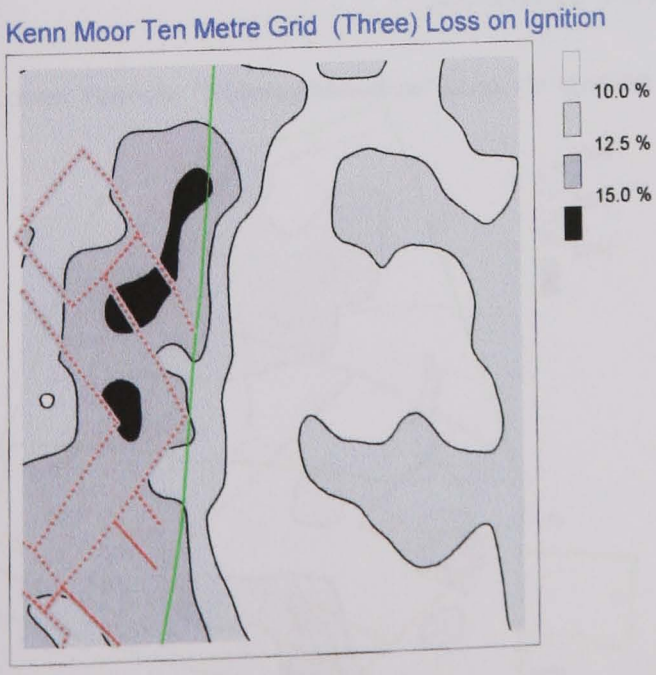
I. Site 4 (page 152)



J. Site 4 (page 152)



K. Site 4 (page 152)



L. Site 4 (page 152)

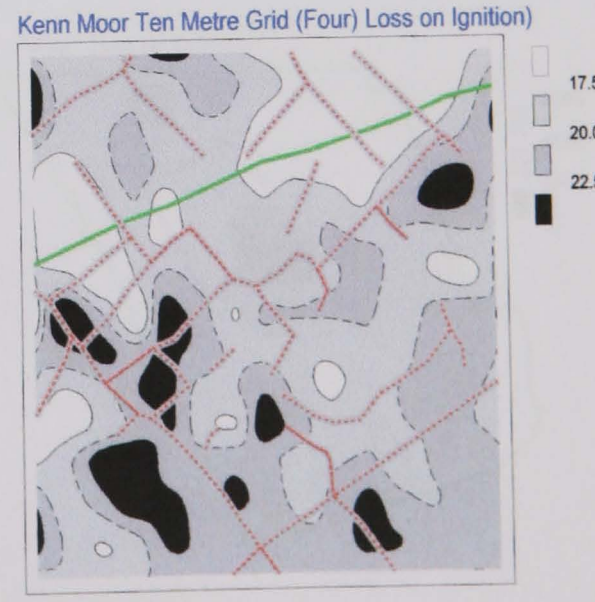
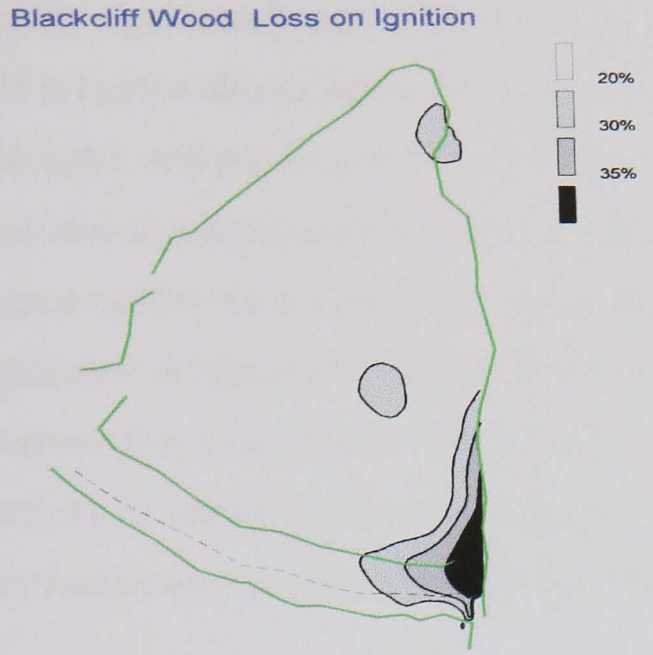
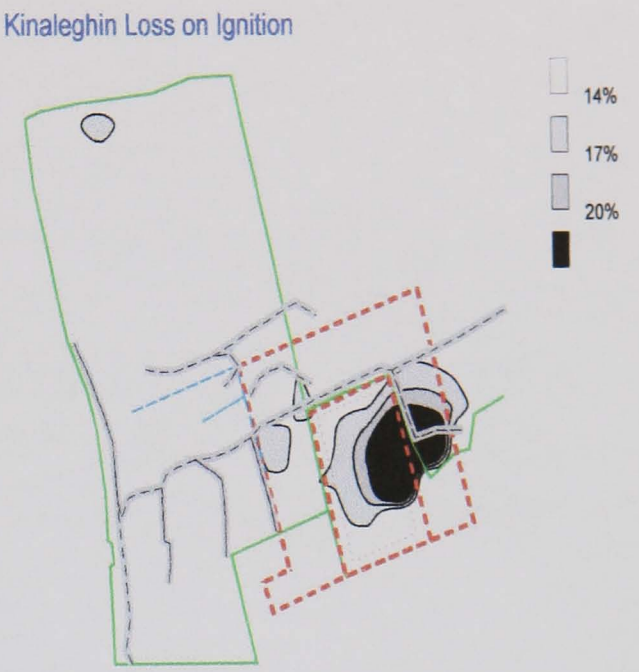


Figure 5.4 (Continued) Loss on Ignition Isoline Maps

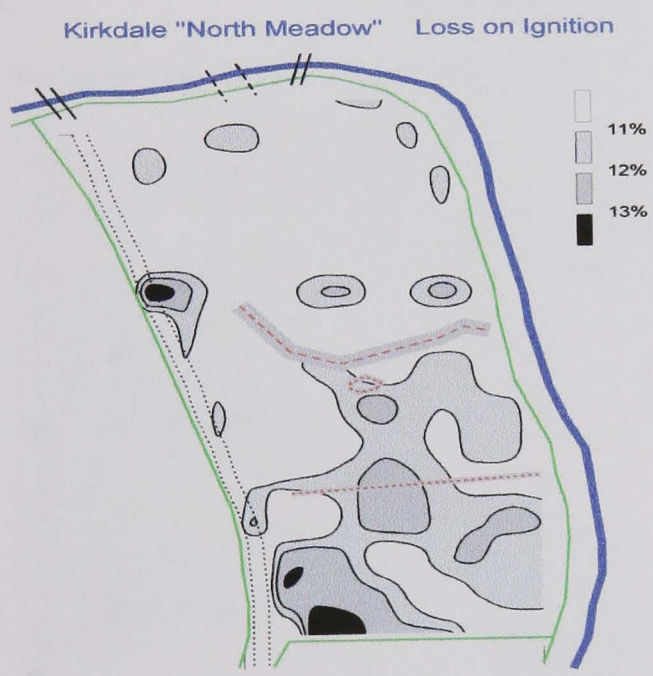
M. Site 9 (page 169)



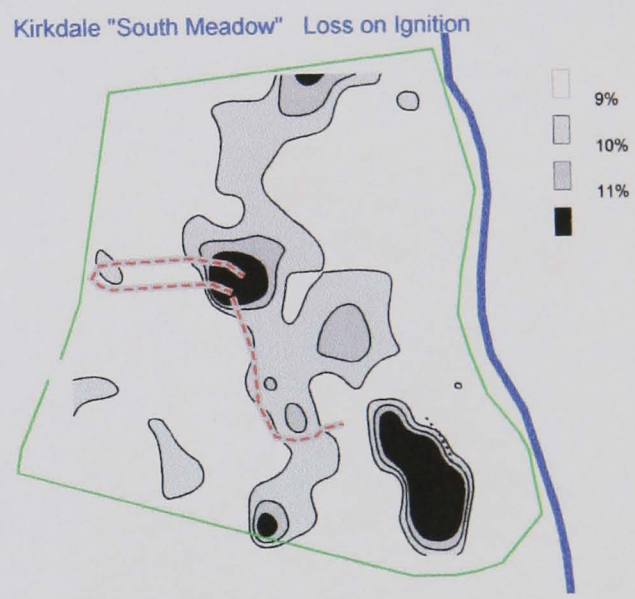
N. Site 12 (page 178)



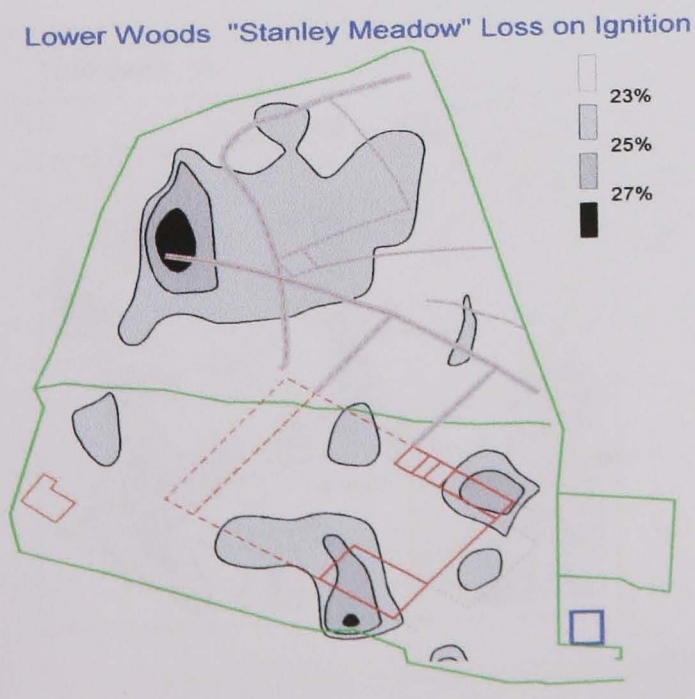
O. Site 11 (page 175)



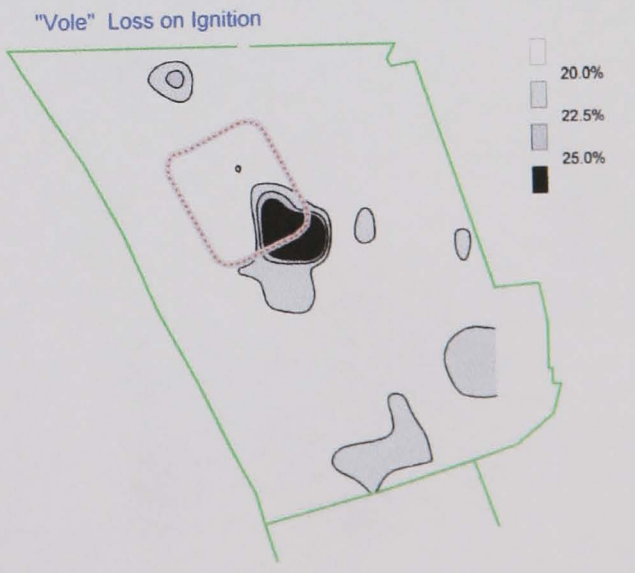
P. Site 10 (page 173)



Q. Site 8 (page 165)



R. Site 6 (page 160)

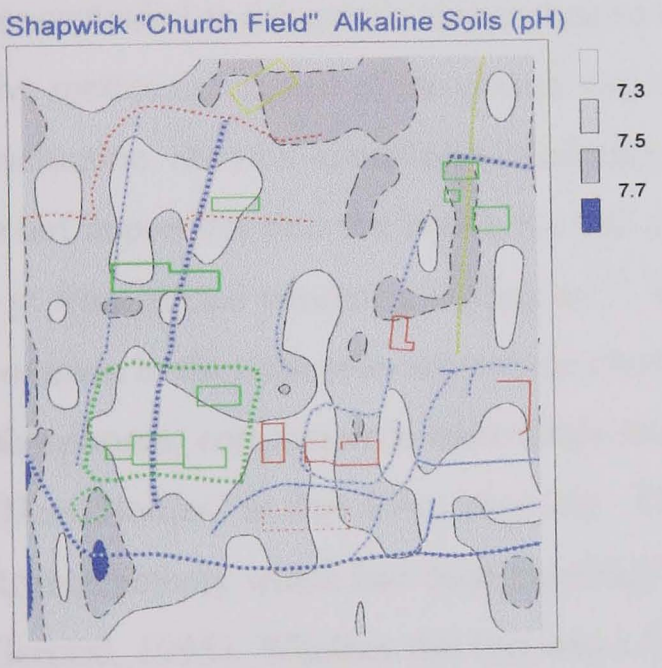


pH

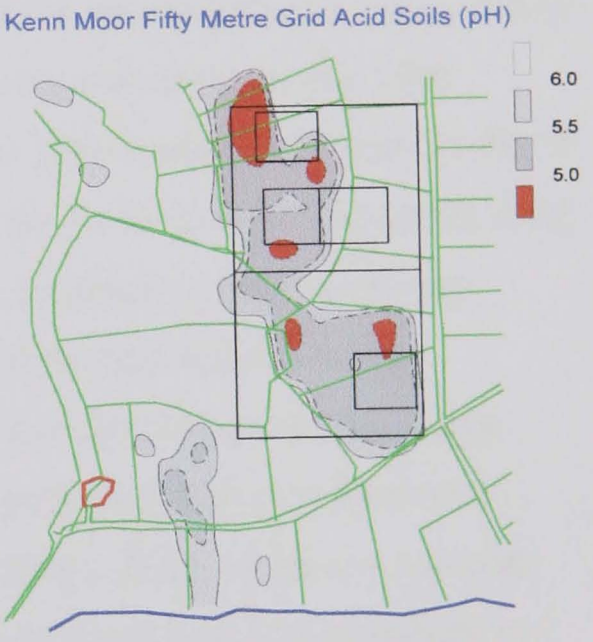
The testing of laboratory dried soils for pH was initially undertaken to check if soil acidity significantly influenced the retention of diagnostic ions, particularly heavy metals. pH is known also to affect the solubility of metals and their potential to be leached from the upper soil profile (see Part 2). In the range of soil pH encountered these factors were not seen to play an important role. Nevertheless the opportunity was taken to test this soil factor against the archaeology. The results were not conclusive. Soils from the medieval enclosure in Shapwick "Church Field" were slightly more acid than those immediately surrounding it (see Figure 5.5 A), as were the soils in the known zones of past human activity on Hamm Farm (see Figure 5.5 B …but see later). On the other hand soil from settlement area at Kinaleghin and the ditch infill at

Figure 5.5 **pH Isoline Maps**

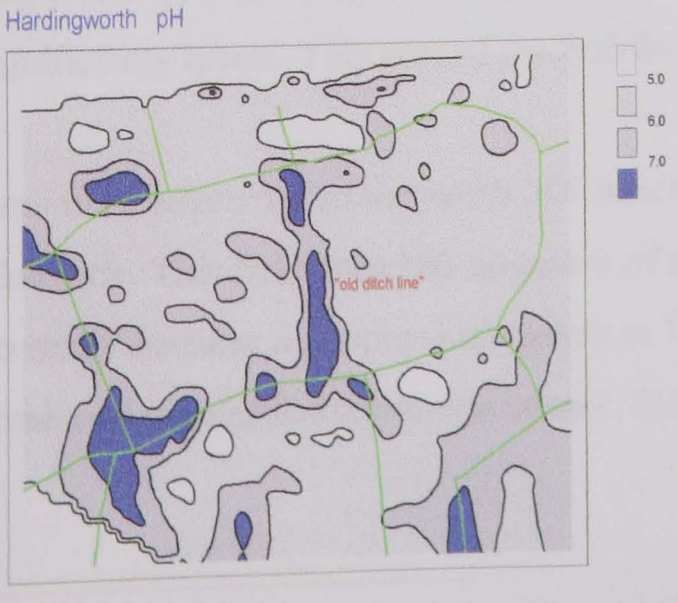
A. Site 1b (page 135)



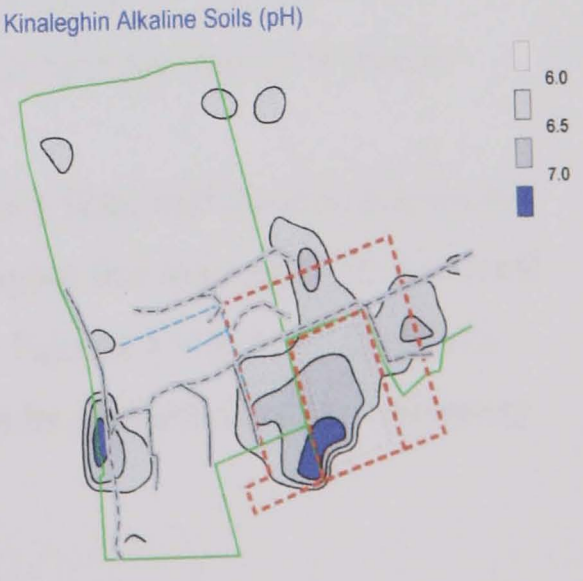
B. Site 4 (page 152)



C. Site 7 (page 163)



D. Site 12 (page 178)



Hardingworth (see Figures 5.5 C & D) were more alkaline than other areas. Some changes in soil pH are associated with past human activity but what they might be attributable to is, as yet, unclear.

C. HEAVY METALS

Lead

Of all the metals tested for, and indeed out of all the factors included for soil evaluation in this dissertation, lead proved to be the most consistent indicator of human activity (see Table 5.3).

The studies at Shapwick were particularly illustrative. The 1996 evaluation of Church Field, Shapwick (15 metre grid) identified an elevation of lead within the soil in the north eastern quarter the field (see Figure 5.6 A). This was largely contained within the limits (defined by a buried Roman ditch) of the multi-period settlement area and concentrated in a crescent-shape close to the site of the medieval church. Some twenty five metres to the east of the church was another concentrated patch. The 1998 evaluation showed remarkable consistency with the 1996 evaluation (Figure 5.6 B). It is not impossible that the lead in the soil derived from the structure of the church itself, e.g. from leaded windows, roofing etc[68]. However, fragments of bone were very common in the dark soils around the church site and the lead (and indeed the phosphorus) enrichment is more likely attributable to cumulative inhumations (see "Dead Bodies" in Part Two, page 20). The patch to the east was associated with Roman activity which had been identified through field walking evidence (Aston & Gerrard, 1995). Whether this too was a burial area is speculative. It is of interest to note that the soil lead concentration over the eastern half part of the church (which might also be older than the western half - Gerrard, pers. com. - See Part 4) is significantly lower. This part of the building may well have pre-dated the burials.

Less the a kilometre to the north of Church Field lies a field, half the size, known as Sladwick. This field drew the attention of archaeologists first because of its name and secondly because a geophysical survey in 1995 (see Figures 4.9 & 4.10) revealed a small rectangular feature in one corner. Soil analysis by students from the University

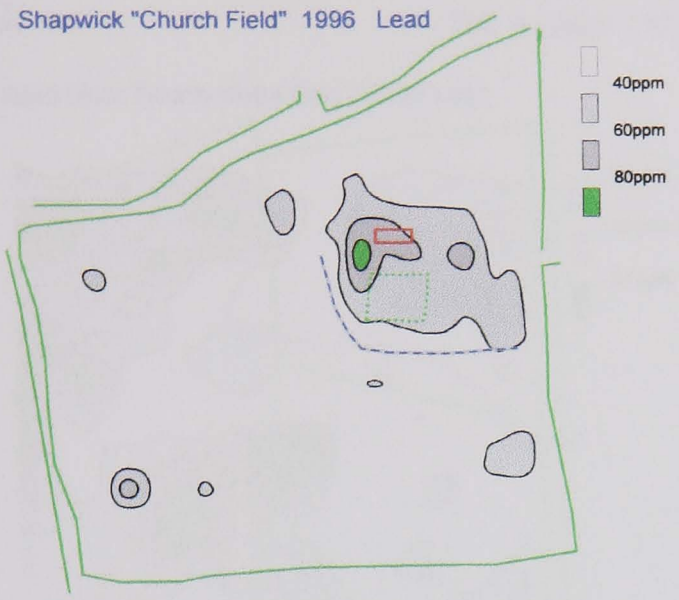
[68] There is some question whether such features were used in a construction of this status at that time – Aston, pers. com.).

Figure 5.6 shows the isoline maps for lead distribution for the twelve sites (18 evaluations – for "Henry" see Fig. 5.2) examined.

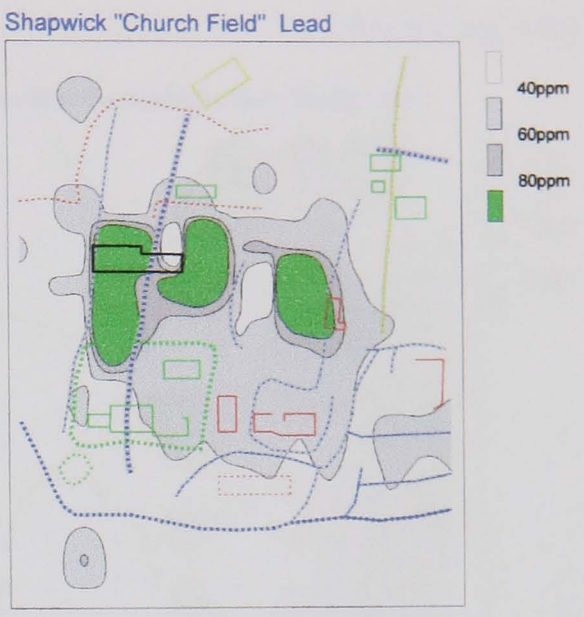
The intervals on isoline maps are set at 1.0 sd (or 0.5 sd for Hardingworth *5.6 E*), 2.0 sd and 3 sd above the mean

Figure 5.6 Lead Isoline Maps

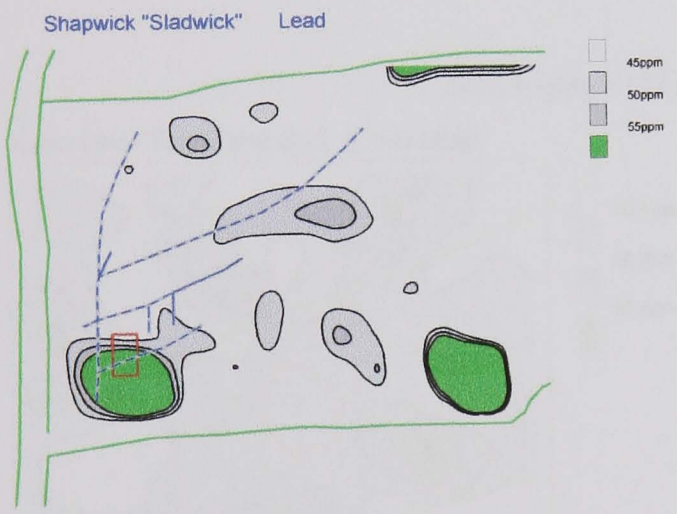
A. Site 1a (page 135)



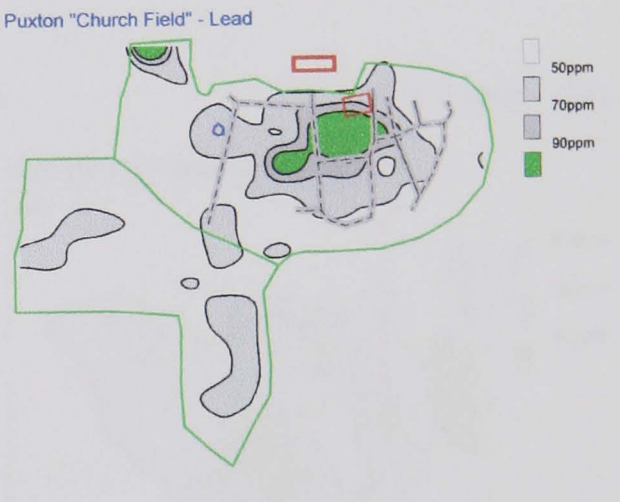
B. Site 1b (page 135)



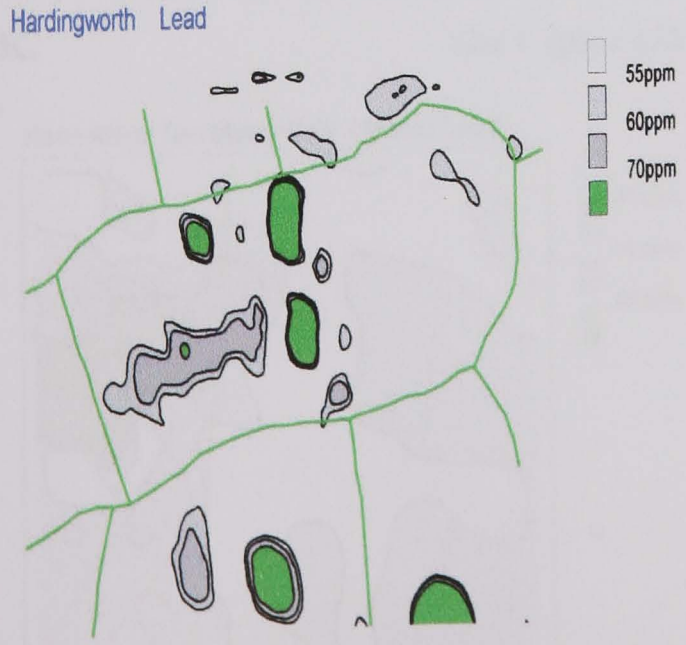
C. Site 3 (page 145)



D. Site 5 (page 156)



E. Site 7 (page 163)



F. Site 4 (page 152)

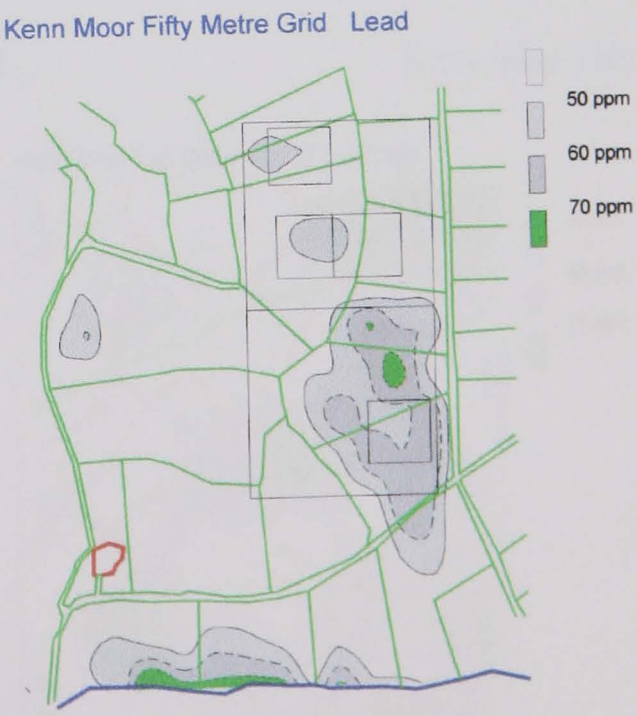
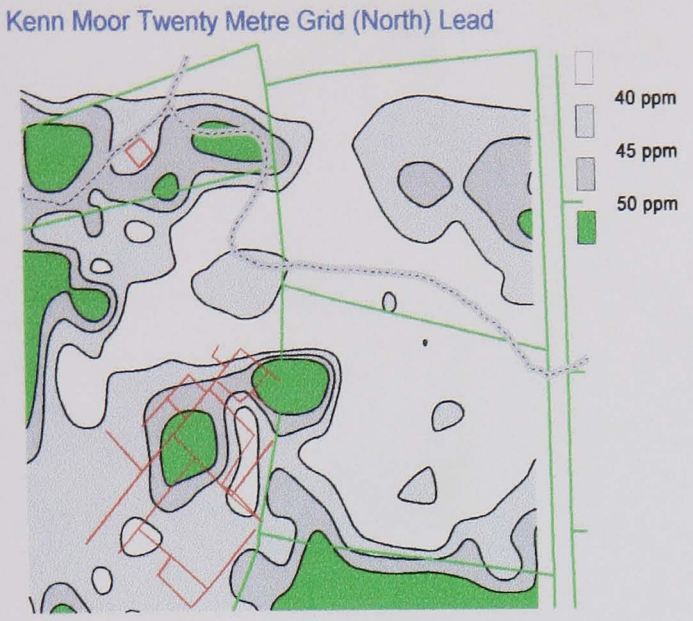
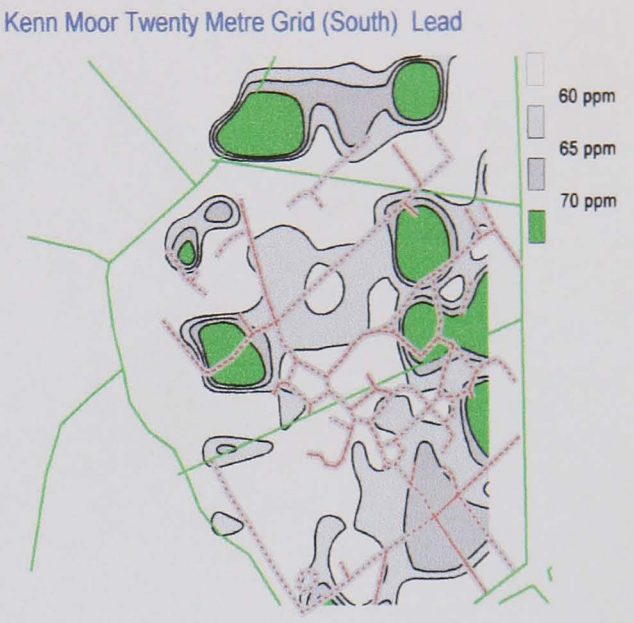


Figure 5.6 (Continued) Lead Isoline Maps

G. Site 4 (page 152)

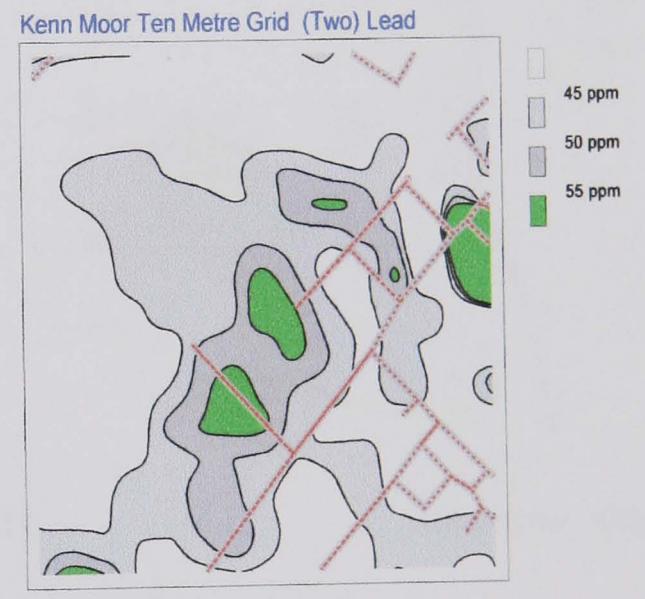


H. Site 4 (page 152)



I. Site 4 (page 152)

J. Site 4 (page 152)



K. Site 4 (page 152)

L. Site 4 (page 152)

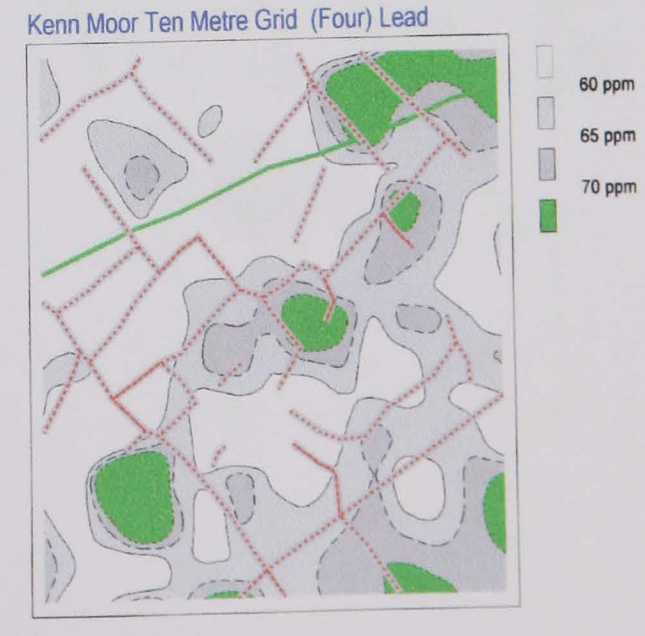
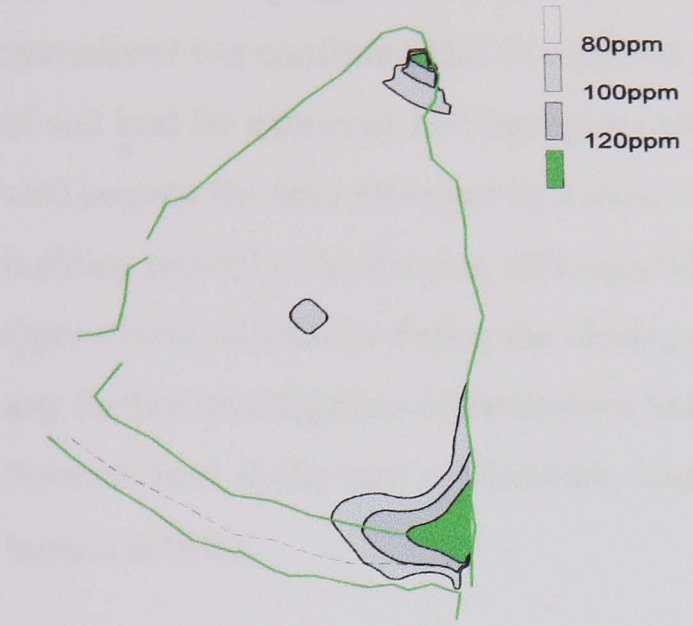
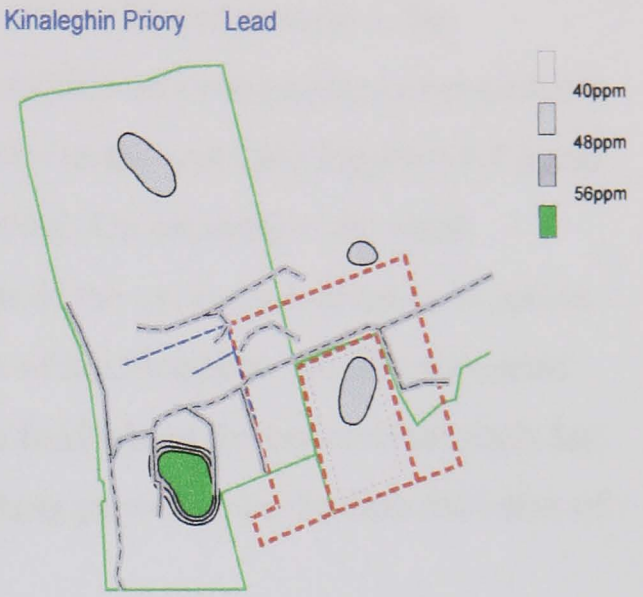


Figure 5.6 (Continued) Lead Isoline Maps

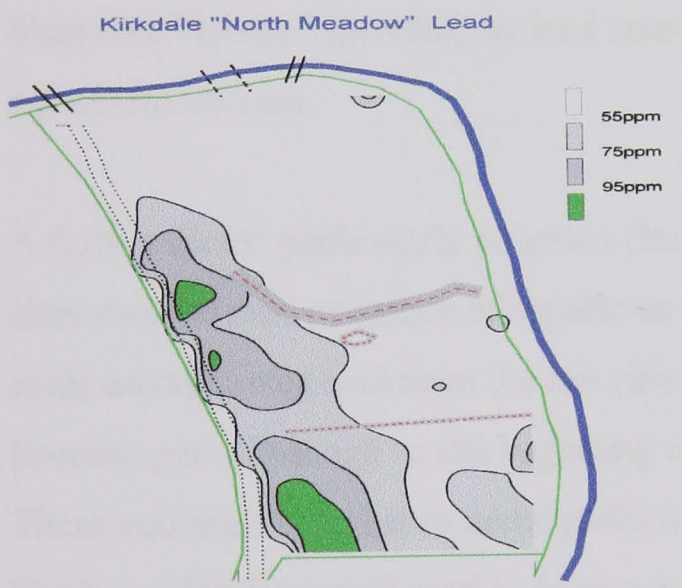
M. Site 9 (page 169)



N. Site 12 (page 178)

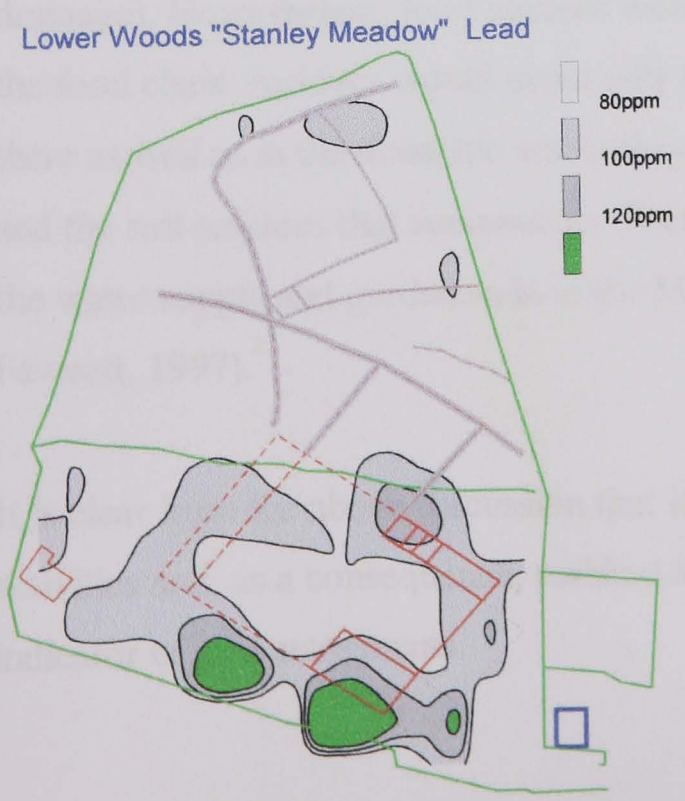


O. Site 11 (page 175)

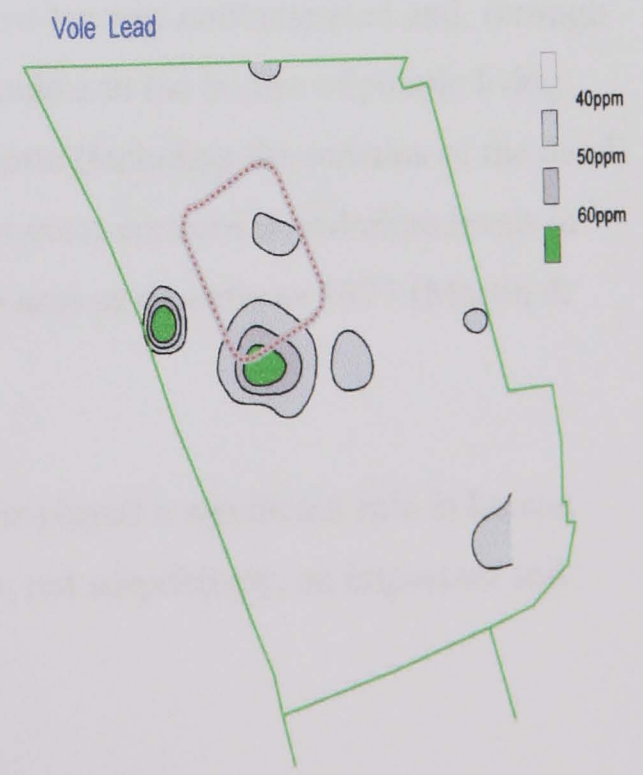


P. Site 10 (page 173)

Q. Site 8 (page 165)



R. Site 6 (page 160)



of Bristol (Farmer, 1996; Bartley, 1996) indicated heavy concentrations of lead (in excess of 100 mg/kg) coincident with the position of the buried structure. Re-assessment has confirmed this finding and also identified an even greater concentration of soil lead (in excess of 150 mg/kg) localised 120m to the east (See Figure 4.6 C) and well beyond the area surveyed by Farmer and Bartley. On excavation the small building proved to be Roman, although full details of the excavation await publication. Operational difficulties during the closing months of the Shapwick Project prevented any further investigation of the eastern half of the field where the untested anomaly lay. Nevertheless, in the case of Sladwick, lead singularly proved to be the best indicator of human activity.

The possible causes for the enhancement of soil-lead in the old orchard land at Shapwick "Henry" (possibly by lead arsenate pesticides) has already been discussed in a previous section.

A further factor particularly poignant (but not necessarily exclusive) to the Somerset sites was the past existence of significant industrial activity on the Mendip Hills. Large scale extraction of lead from the ore rich hills dates from the earliest Roman (even pre-Roman) period though to the beginning of the 20th Century (Martin & Fawcett, 1997). These activities have led to aerial pollution of the surrounding countryside Such blanket pollution would tend to have a general effect over the fall-out area varying only with distance from the source and through the effects of winds (and natural drainage). Nevertheless, food sources would have become contaminated and, through the food chain, residues would eventually accumulate in the bodies of people living there as well as in the domestic waste they generate (including the remains of the dead) and the soil residues that accumulate. There was great concern at cadmium levels in the water supply and garden soils in the Mendip area as recently as 1977 (Martin & Fawcett, 1997).

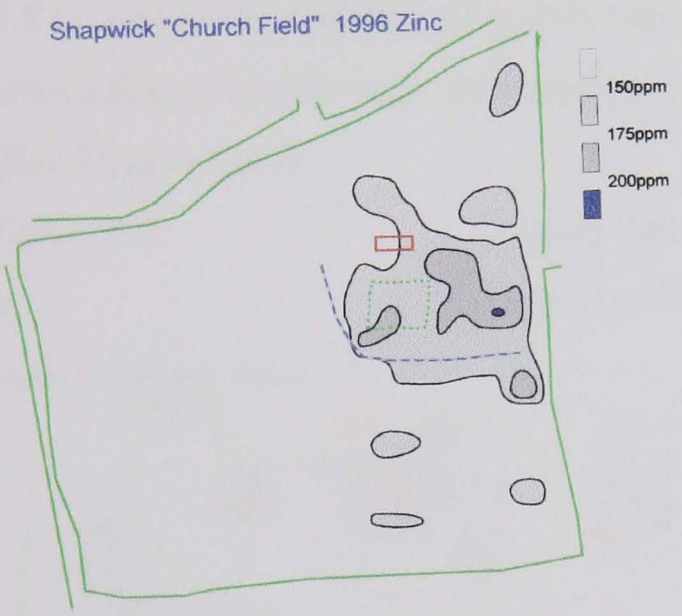
It is clear from the above discussion that lead has played a significant role in human activities and, as a consequence, residual lead is, not surprisingly, an important soil indicator of past settlements.

Zinc & Cadmium

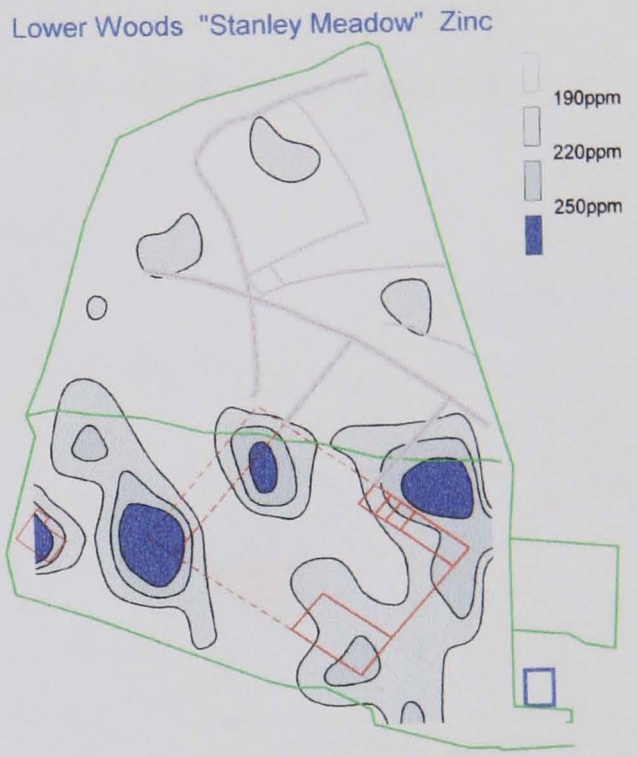
The soil concentrations of zinc and cadmium have also proven to be consistent in its association with human activity (see Figure 5.7). Although zinc can occur in appreciable quantities (> 900 mg/kg), the soil cadmium concentrations seldom exceed 1 mg/kg putting it close to the limit of detection by the methodology adopted in this research.

Figure 5.7 **Zinc and Cadmium Isoline Maps**

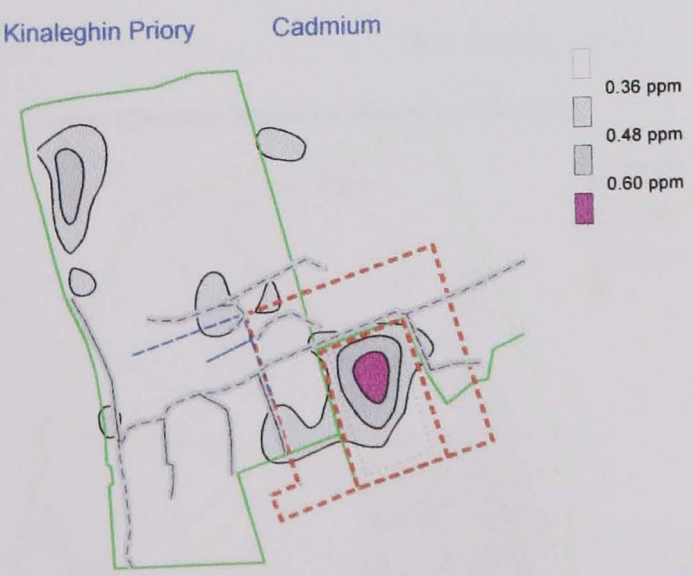
A. Site 1a (page 135)



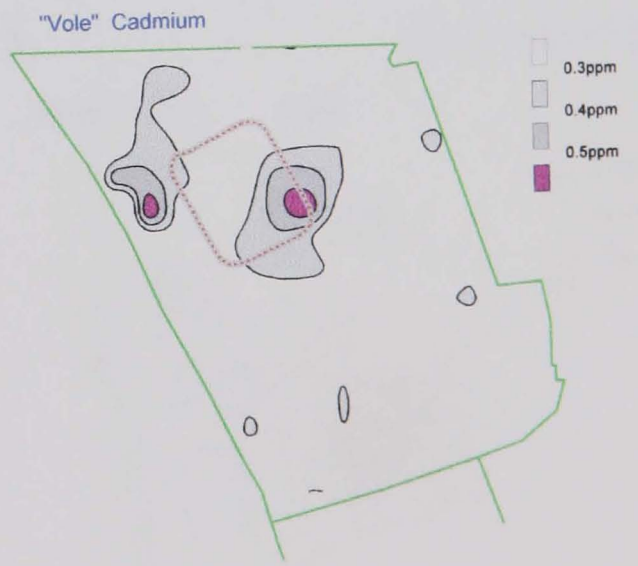
B. Site 8 (page 165)



C. Site 12 (page 178)



D. Site 6 (page 160)

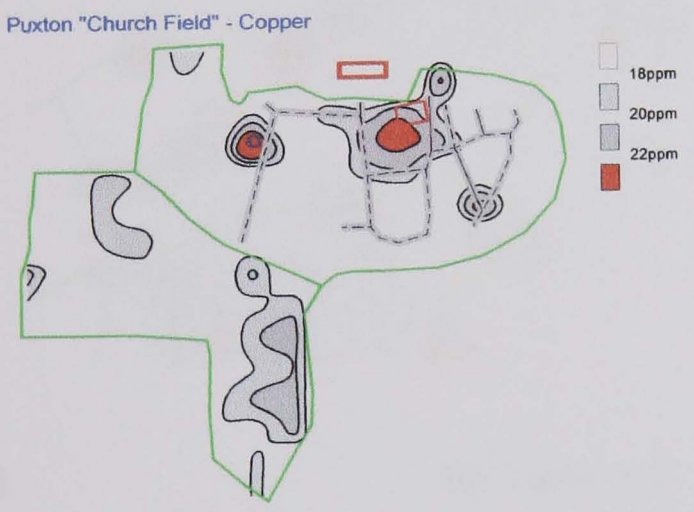


Copper

Of those metals found in this study to be associated with archaeological remains, copper is the most enigmatic. Enhanced levels co-incident with the settlements at Puxton, Vole, Lower Woods and Kinaleghin demonstrated a close association (See Figures 5.8 A, B, C & D). Results from Shapwick "Church Field" and, for example, from the post-medieval strip of debris at the west end of Hardingworth, were more equivocal (Figures 5.8 E, F& G). At Kirkdale accumulations of the metal were found in the (older) riverine deposits and it is speculated that these were not locally generated (Figures 5.8 H). At Hamm Farm copper evaluations revealed an interesting but unexplained band running diagonally across the postulated Roman farmstead (Figures 5.8 I). Just to the north of the present farmhouse (see Figure 4.13) an interesting association of copper with other elements came to light and this is discussed below (See Figures 5.8 J).

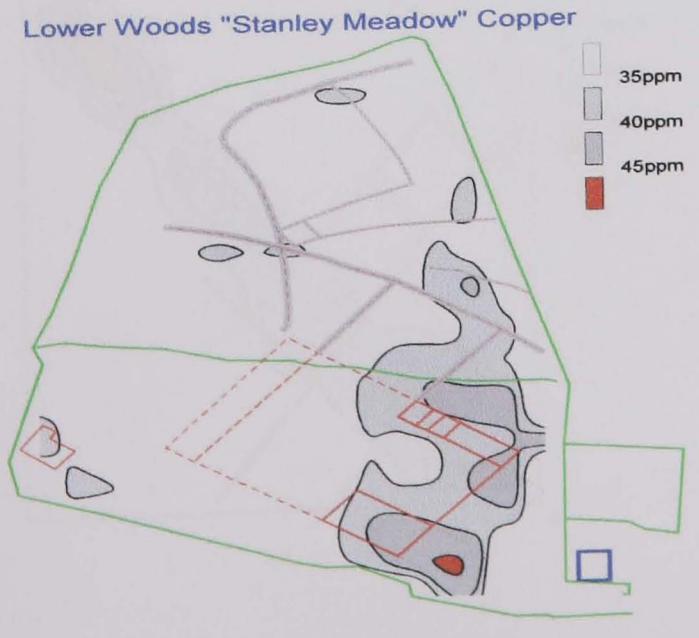
Figure 5.8 **Copper Isoline Maps**

A. Site 5 (page 156)



B. Site 6 (page 160)

C. Site 8 (page 165)



D. Site 12 (page 178)

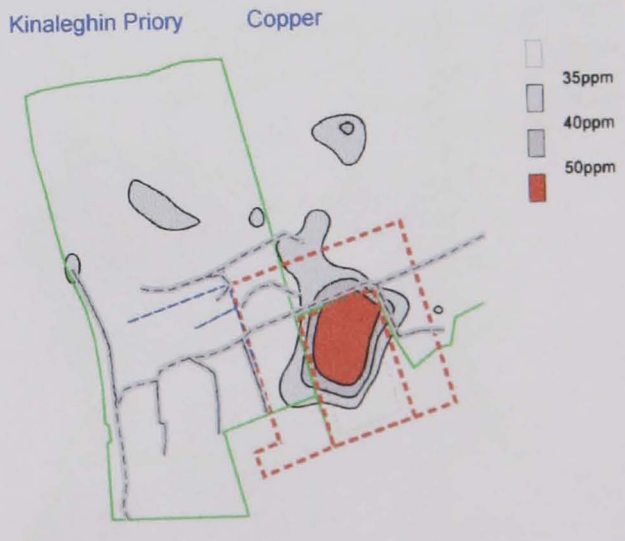
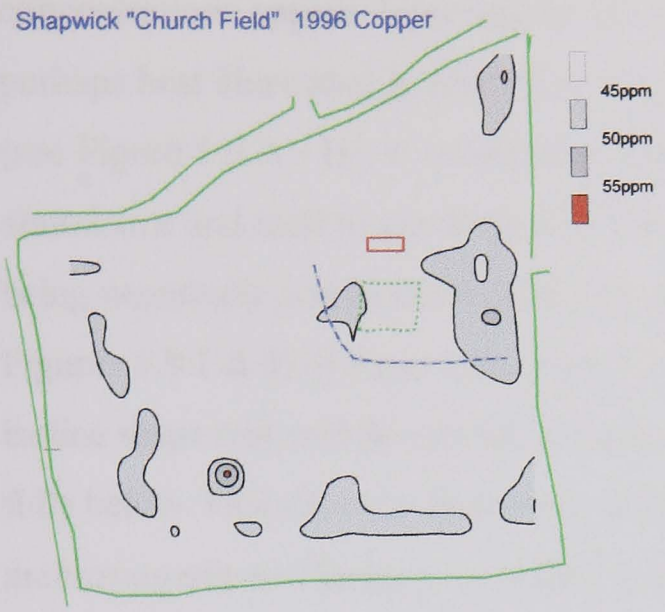
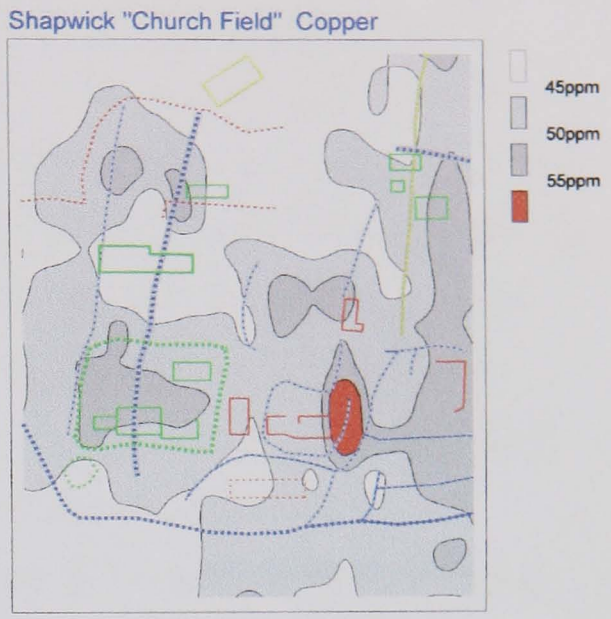


Figure 5.8 (Continued) Copper Isoline Maps

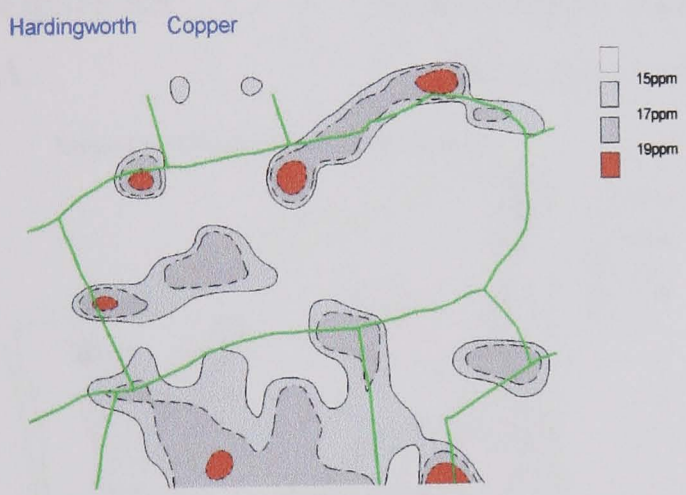
E. Site 1a (page 135)



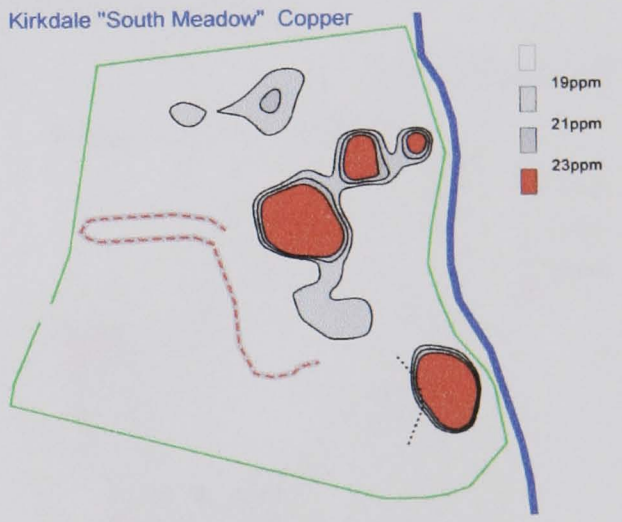
F. Site 1b (page 135)



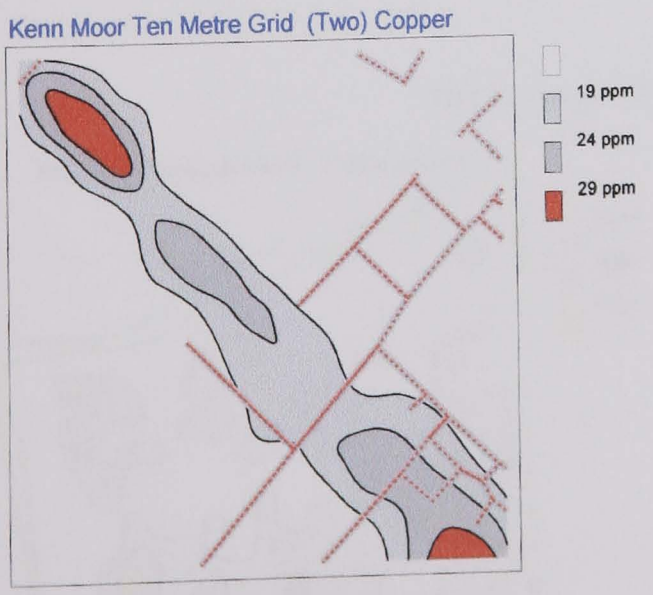
G. Site 7 (page 163)



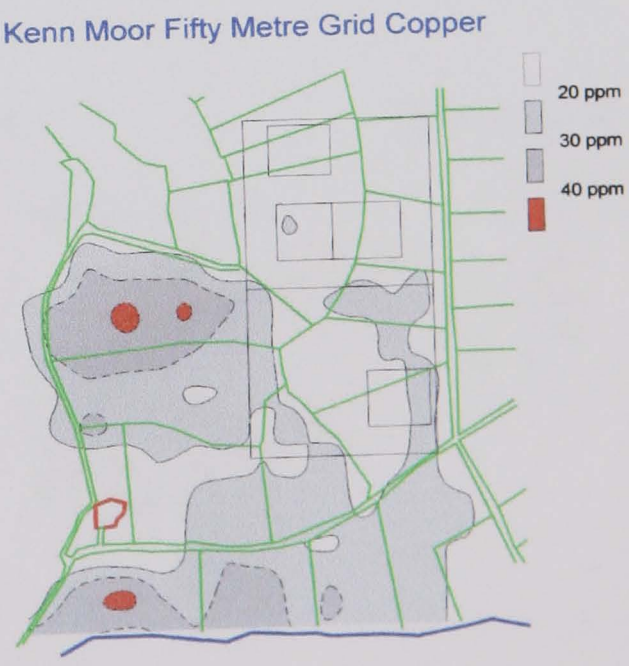
H. Site 10 (page 173)



I. Site 4 (page 152)



J. Site 4 (page 152)

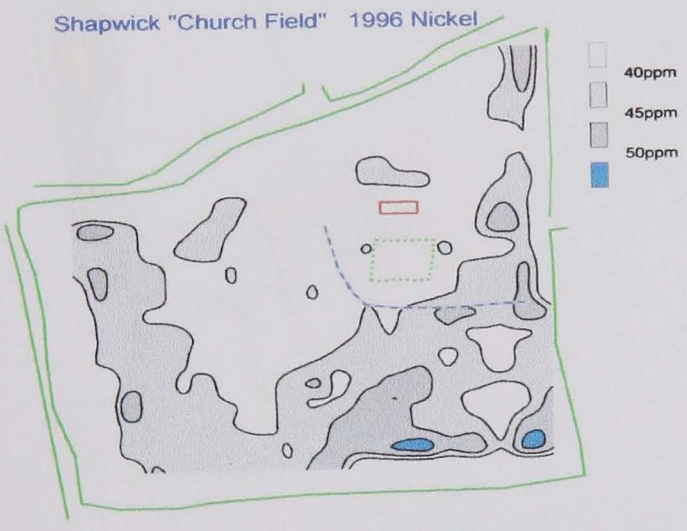


Nickel, Cobalt & Chromium

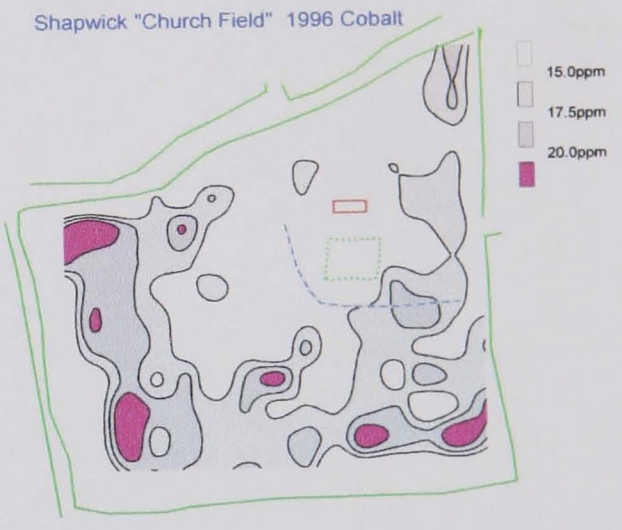
These three elements set themselves apart from the other soil factors in that soil concentrations appear depressed in the environs of past human settlement. This is perhaps best illustrated at Shapwick "Church Field", Puxton , Kinaleghin and Vole (see Figure 5.9 A - H). It is probable that these elements are not accumulated in such abundance and tend to get diluted by those that are. Hence they give the appearance of being negatively correlated with human activity. Plotting reciprocal values (compare Figures 5.9 I & J) of these apparently "non-anthropogenic" elements can produce isoline maps that match with the archaeology. The "dilution effect" is discussed more fully below. Occasionally there is a coincidence of anthropogenic and non-anthropogenic soil factors, so called "hot spots" such as the "pit" in Puxton "Church Field": sometimes chromium is less consistent in its disassociation with human activity. Both these anomalies are discussed later in this text.

Figure 5.9 **Nickel, Cobalt and Chromium Isoline Maps**

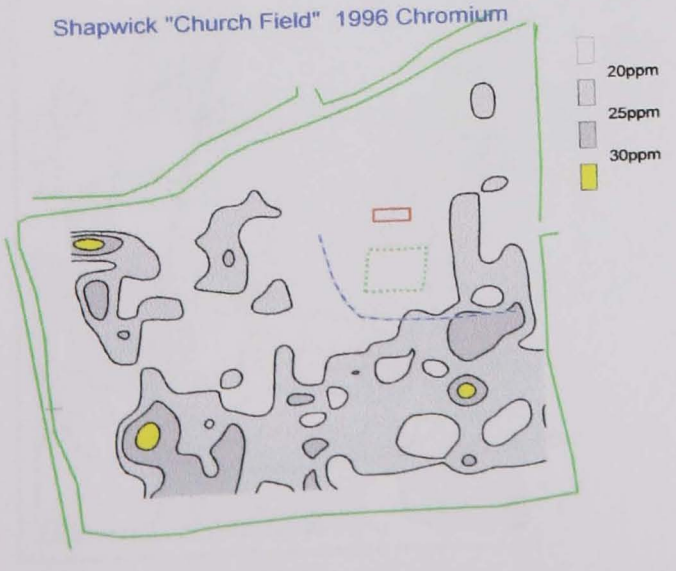
A. Site 1a (page 135)



B. Site 1a (page 135)



C. Site 1a (page 135)



D. Site 5 (page 156)

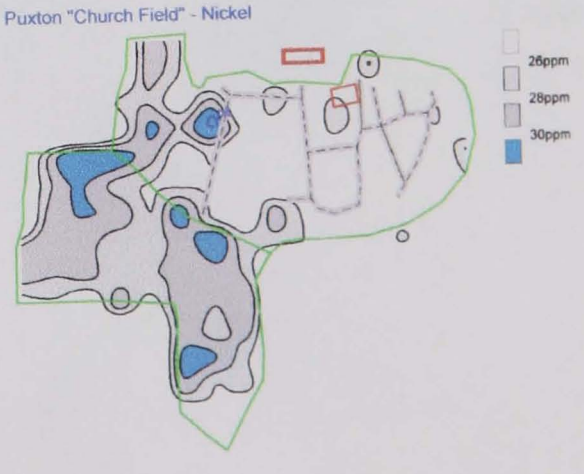
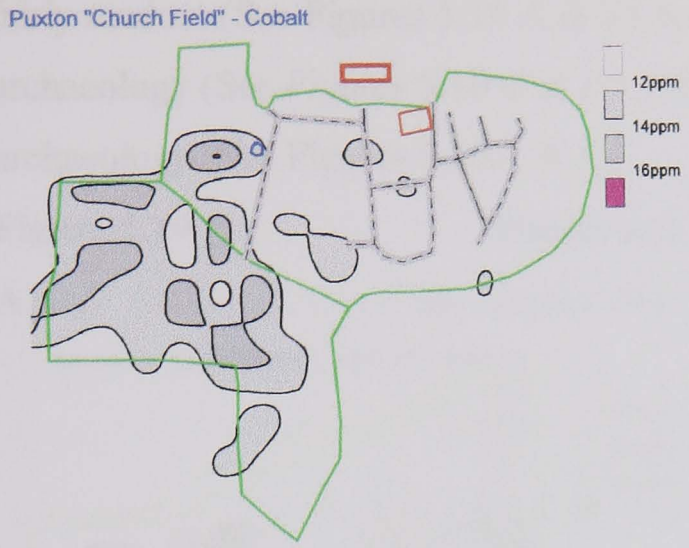
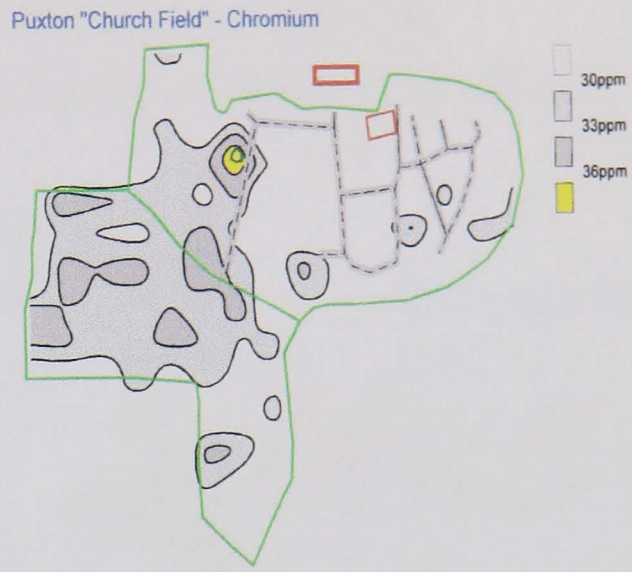


Figure 5.9 (Continued) Nickel, Cobalt and Chromium Isoline Maps

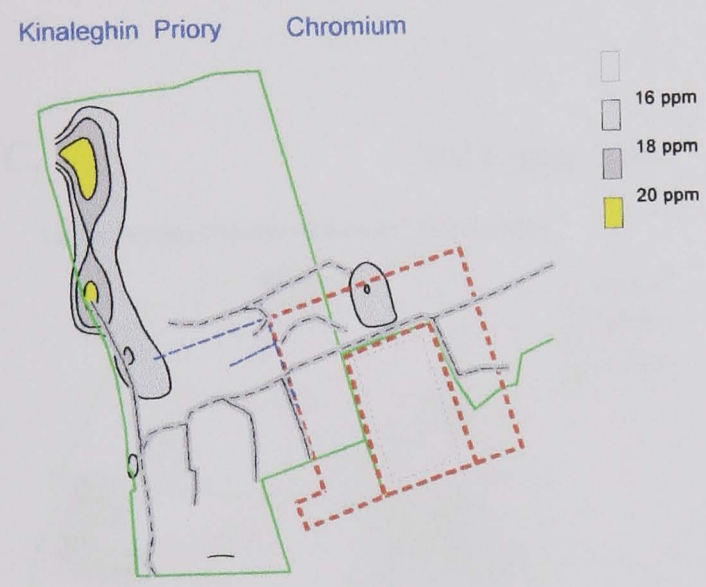
E. Site 5 (page 156)



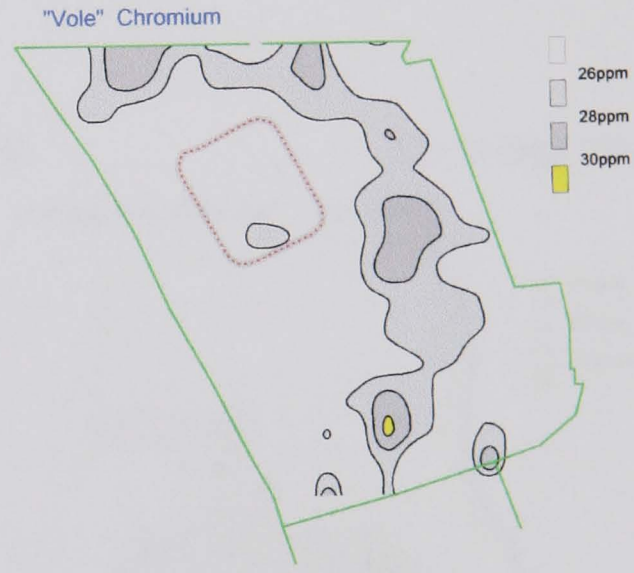
F. Site 5 (page 156)



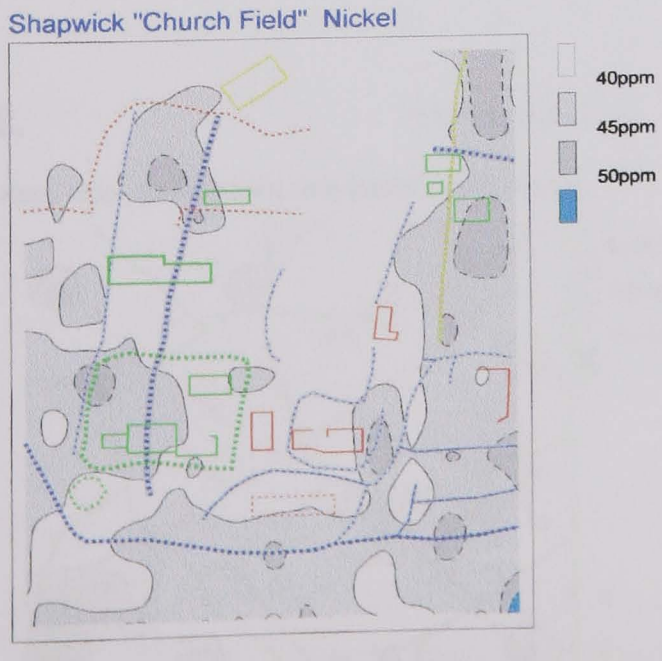
G. Site 12 (page 178)



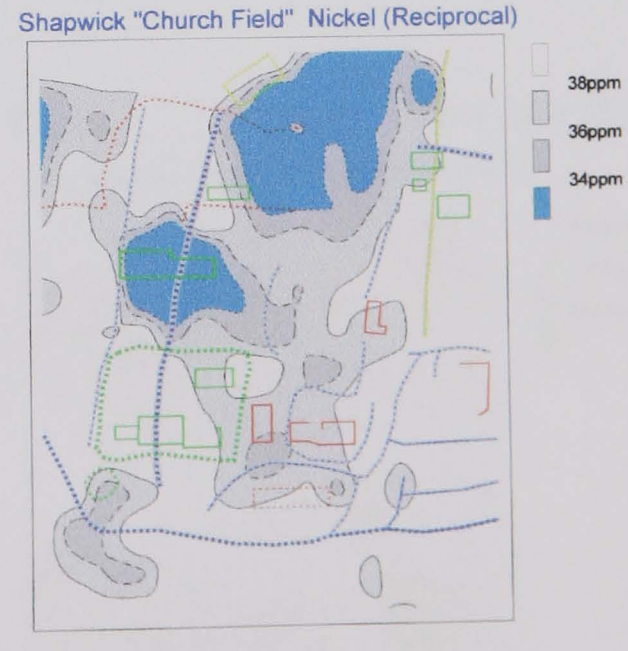
H. Site 6 (page 160)



I. Site 1b (page 135)



J. Site 1b (page 135)

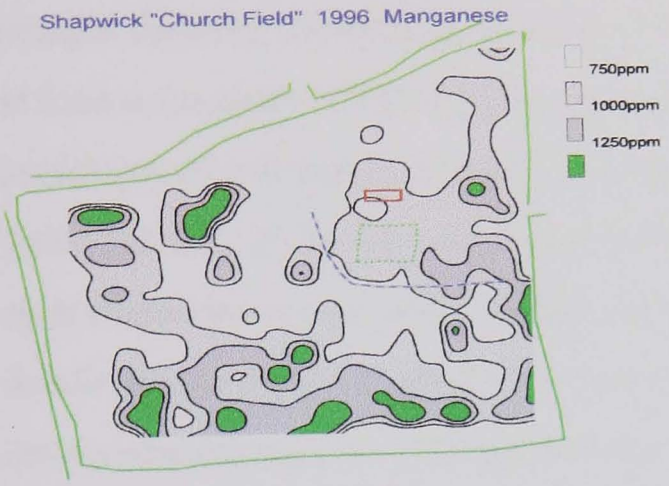


Manganese

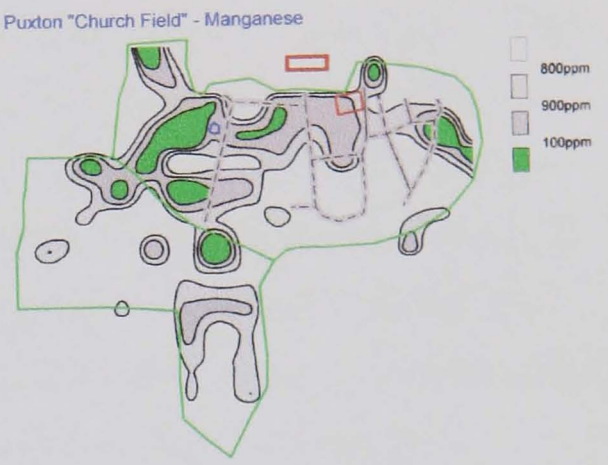
This is the least consistent of the heavy metals tested. Distribution, in most cases seems fairly random (See Figures 5.10 A & B) but is sometimes associated with the archaeology (See Figures 5.10 C & D) and in other instances is disassociated with the archaeology (See Figures 5.10 E & F).

Figure 5.10 **Manganese Isoline Maps**

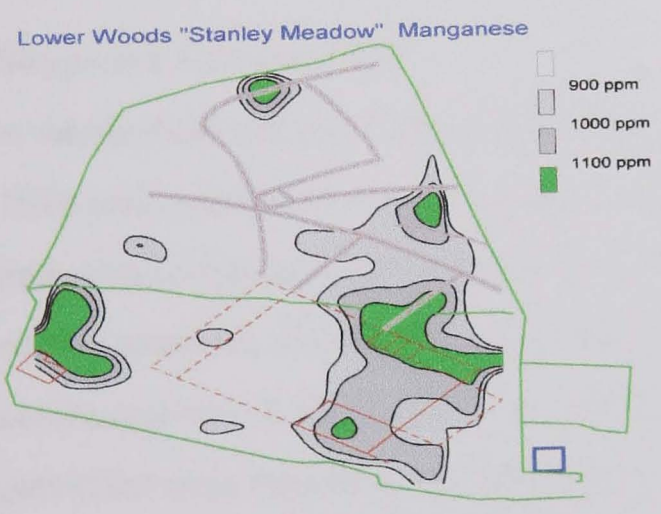
A. Site 1a (page 135)



B. Site 5 (page 156)

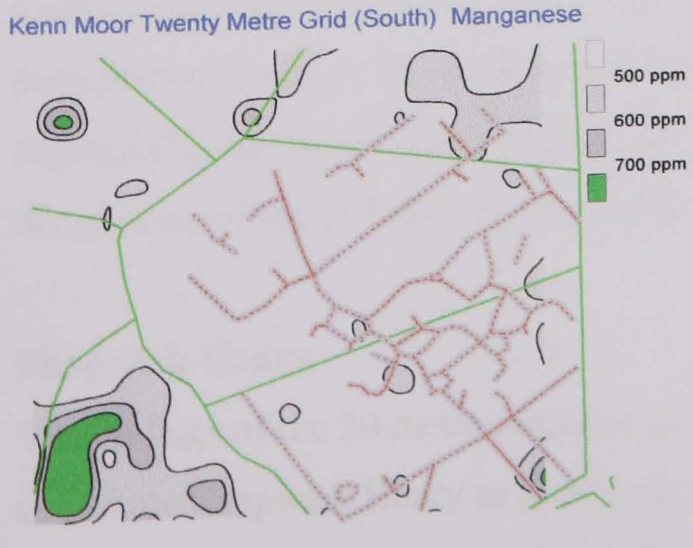


C. Site 8 (page 165)

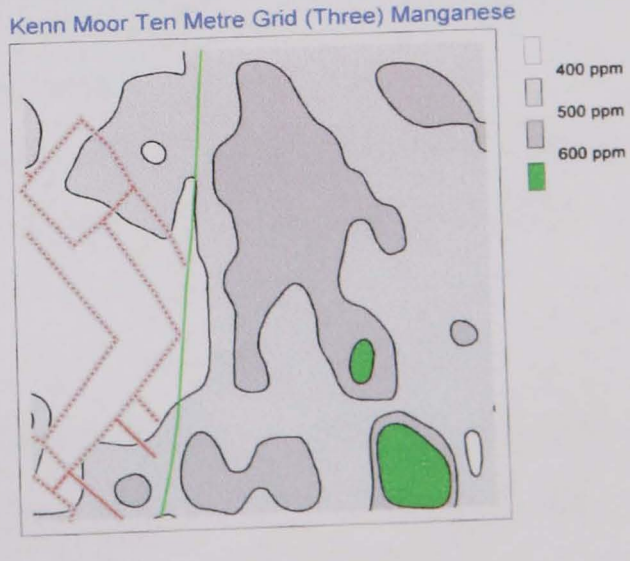


D. Site 10 (page 173)

E. Site 4 (page 152)



F. Site 4 (page 152)



D. SUMMARY

It was the intention from the outset of this thesis to use the results of the soil analyses selectively as arguments for the proposed hypotheses and not to produce a site by site evaluation. Archaeological evidence at some sites is sparse and at some fortuitous. The demands of soil analysis left little time for corroboratory excavation. Although the work has produced a great deal of analytical data from which basic principles can be drawn, at this stage in the research, the interpretation of individual sites is not at all straight forward. Nevertheless, it was felt that the report would be incomplete without at least a summary of the findings from each site. This is presented below. The usefulness of soil factor evaluation is summarised at the end of the sub-section in Table 5.3 and, in the following sub-section, in Table 5.4. The descriptive statistics of each evaluation are presented at the end of this volume in Appendix I. Further site details, all the isoline maps and the statistical analyses can be found in Appendix II (on the accompanying CD). The isoline maps in Appendix II have been arranged according to site and it is suggested that the following summary is read in conjunction with that compilation on the CD.

Shapwick Church Field

A whole-field survey of Shapwick Church Field was conducted on 15 metre grid in 1996 and constituted part of a master's degree that preceded the present study. The inclusion of this survey enabled a re-working of the data and a comparison with further survey material. The later survey (of the northeast corner of the field) in 1998 was conducted on a 5 metre grid and included a partial repetition of the earlier survey. Of particular note was the close co-incidence of phosphorus, organic carbon, lead, zinc and magnetic susceptibility with the settlement zone and the disassociation of nickel, cobalt and chromium. Neither copper nor cadmium demonstrated a convincing co-location with the "known" zone of past human activity. There was a close spatial coincidence between the findings of both surveys which indicated, at least, the repeatability of the process. The later intensive survey presented greater detail in the distribution of the soil factors demonstrating the complexity of this multi-period site.

Shapwick Henry

The findings of the 20 metre sampling grid of four out of the five intended fields that constitute Shapwick Henry to some extent matched those of Shapwick Church Field but had little archaeology to corroborate the recorded distribution of soil factors.

Nevertheless, phosphorus and organic carbon distribution was well matched and clearly dissociated with the other soil factors except perhaps lead and magnetic susceptibility. With no hard archaeological evidence to go on the soil patterns were attributed to more recent agronomic activity.

Shapwick Sladwick

Shapwick Sladwick was perhaps the most frustrating of the sites. Soils were sampled on a 20 metre sampling grid across most of the field. There was a marked coincidence of lead with what later excavation proved to be a small Roman building. Phosphorus, copper and magnetic susceptibility enhancements were associated with the area of human activity as defined by geophysical survey, but so too were the usually site-negative elements nickel and cobalt. Organic carbon-rich soils were not obviously associated with any known archaeology and a further lead-rich patch, possibly indicative of another Roman building, could not be examined as access to the site was denied.

Hamm Farm

The Hamm Farm site in North Somerset was the most ambitious of the evaluations undertaken covering a total of 60 hectares and including sampling on 50, 20 and 10 metre grids. Over 1 tonne of soil was processed and the full analysis of the resulting data still awaits completion. Although a complete set of isoline maps is presented either in the text or in Appendix II (on the CD), time has not allowed for more than a partial reporting of the site in this thesis. The presented summary provides some interpretation of the site as a whole.

Soils enriched with phosphorus, organic carbon, lead, zinc, and cadmium were clearly coincident with areas of known archaeology and the greater concentrations of the heavy metals nickel, cobalt and chromium proved to be non site related. These potentially organic matter derived residues were also prolific along the edges of the Little River and may well indicate dredging deposits or the anaerobic preservation of plant material in wet and waterlogged conditions. Soil concentrations of copper were anomalous but demonstrated peculiar concentrations to the north of the present farm house (and across the conjectured site of the Roman farmhouse (Ten Metre Grid Two) that warrant further investigation. At this site the soil magnetic susceptibility was not indicative of the known archaeology.

Hamm Farm, being such a large site, provided an insight into the influences of both geology and agronomy on the pattern of soil factor distribution. Soils in the archaeologically and organically rich parts of the farm were much more acid (pH < 5.5). Although these factors might not be so important in an intra-site evaluation they certainly are important when comparing sites or in any attempt to define type archaeological signatures.

Puxton Church Field

Church Field was the second of the two sites that were originally part of the preceding MA dissertation (Jackson, 1997) but re-assessed in the light of new data. This field, together with a second field to the south which had little evidence of past settlement activity, were sampled on a 20 metre grid. Soils from the eastern half of Church Field, in which most of the earthworks were concentrated, were markedly richer in phosphorus, lead, copper, zinc, cadmium and, to an extent, organic carbon whereas the higher concentrations of nickel, cobalt and chromium were in the field to the south and away from the focus of past activity. The more ambiguous spread of organic carbon rich soils is perhaps an indication of more recent deposits similar to those described at Hamm Farm. Neither magnetic susceptibility nor pH measurements were taken at this site. Just to the west of the earthworks was a small depression soils from which were relatively rich in most of the tested for soil factors. Deteriorating weather prevented archaeological investigation of this feature and any interpretation of what it might have been remains unresolved.

Vole Farm

Soils taken on a 20 metre grid from the 4 ha field to the west of Vole Farm showed some of the clearest associations of phosphorus, pH, magnetic susceptibility, lead, copper, zinc and cadmium with the area of visible earthworks. An extremely rich patch of soil zinc to the south east of the earthworks coincided with the location of a galvanised water trough. The disassociation of nickel, cobalt and chromium were similarly clear.

Hardingworth

With only the field name to go on, Hardingworth, presented some what of a challenge. The field, together with parts of the surrounding fields were sampled on a 20 metre grid. It had been hoped that evidence of a medieval settlement might be forthcoming. In the event three areas of suspected site-positive soil factors enhancement within caught the eye. A band of more alkaline soil with elevated levels of magnetic susceptibility, and lead was identified as infilled field boundary ditch; an enrichment of phosphorus and organic carbon under tall trees to the north east of the field was possibly attributed to a place of shelter favoured by livestock; leaving an east / west band of phosphorus, organic carbon, lead, copper, cadmium and zinc at the west end of the field. Archaeologists from the University of Exeter were able to throw a trench across this band and discovered it coincided very closely with a deposit of post-medieval debris. Again the site-negative association of nickel, cobalt and chromium was observed.

Lower Woods

Two adjoining meadows set within the South Gloucestershire woodlands of Lower Woods provided a suitable area for soil sampling. The recovery of appreciable amounts of Roman pottery from the surrounding wood banks and from post holes dug for a new fence prompted soil sampling on a twenty metre grid across both meadows. Soils enriched in phosphorus, organic carbon, magnetic susceptibility, lead, copper and zinc were concentrated at the eastern end of the southern meadow. A follow up geophysical survey (Resistivity) reveal a clear coincidence with a buried feature that is almost certainly a complex of Roman buildings. Elevations in organic carbon in the western end of the northern meadow was associated with waterlogged soils. Cadmium did not prove to be a good indicator but, once again, the higher concentrations of nickel and chromium were shown to be negatively site-related. (Neither pH nor cobalt were assessed at this site).

Blackcliff Woods

Apart fro the perimeter bank, a ditch, the gateway, and a recent charcoal platform no other settlement or human activity features were identified at this conjectured Dark Age site. Soil samples were taken on a 20 metre grid. Elevated levels of phosphorus, magnetic susceptibility, organic carbon, and lead, copper, cadmium and zinc were associated with the charcoal platform and with the eastern end of the ditch. Nickel and

chromium were nor associated with these features. pH and cobalt were not assessed at this site.

Kirkdale North Meadow

The pasture just to the north of St Gregory's Minster still preserves its medieval ridge and furrow which, in the southern half of the field, overlays the conjectured early medieval settlement. Soil taken on a twenty metre grid across the whole field showed a notable enhancement of phosphorus, magnetic susceptibility, loss on ignition, lead, zinc and cadmium within the southern half with somewhat of a bias away from the river edge towards higher (less floodable?) land. Copper enhancements were more noticeable towards the river edge suggesting the effects of flood deposition from known mineral workings further up stream. Higher levels of nickel, cobalt and chromium were dissociated with soils rich in the other metals. A "spike" in magnetic susceptibility at the north end of the field coincided with the regular site of Boy scout bonfire.

Kirkdale South Meadow

The topography of the meadow to the south of the Minster is more complex than the north meadow having a marked change in elevation from a plateau level on the west dropping to a narrow flat floodplain. Towards the south of the field there is an exposed scarp two metres high separating the area. Most evidence of past settlement (earthworks) lies on the higher land and soils with higher levels of phosphorus, magnetic susceptibility, organic carbon, lead, zinc and cadmium are clearly associated with this area. Nickel, cobalt and again copper richer soils were recovered from the flood plain.

Kinaleghin

There was a very marked association of soils with greater concentrations of phosphorus, magnetic susceptibility, organic carbon, higher pH, lead, copper, cadmium and zinc with the suspected cloister area of the priory. While it is tempting to attribute these soil enrichments with more recent cattle stocking, the extension of some of these enriched soils into adjoining fields suggests a more ancient origin. The outlying patch of lead rich soil amongst the earthworks in the field to the west of the cloister area warrants further examination. The similar patch of zinc-rich soil might

Table 5.3 (Explanatory Notes)

Fit with the archaeology		Score
***	very good	3
**	good	2
*	fair	1
*	neutral	0
*	slightly negative	-1
**	negative	-2
***	very negative	-3
-	missing value	0

Maximum score for the 12 sites is +36

Minimum score for the 12 sites is –36

Fit is calculated as a percentage of the maximum or minimum score as appropriate.

In the case of Nickel, Cobalt and Chromium, which are on balance negatively associated with sites of human activity, reciprocal values could be used to prospect for sites (see for example Figures 5.9 I & J). Reciprocal values of Cobalt, for example (see Table 5.3), would successfully match Magnetic Susceptibility as a site predictor.

well be due to the past siting of a galvanised water trough. Again soil elevations of nickel, cobalt, and chromium are well away from the known archaeology.

Table 5.3 summarises the effective co-incidence of the individual soil factors measured with the archaeological evidence as it is known (note the cautionary comments made at the beginning of this section).

Table 5.3 Soil factor evaluation – Geographical Association (i.e. spatial co-incidence of the highest and lowest concentrations with known human activity)

Site	P	pH	MS	LOI	Pb	Cu	Cd	Zn	Ni	Co	Cr	Mn
Shapwick Church Field (combined)	***	-	*	**	**	*	*	**	**	**	**	*
Shapwick Henry	*	-	*	*	*	*	*	*	*	*	*	*
Shapwick Sladwick	*	-	*	*	***	*	*	*	**	*	*	*
Hamm Farm (combined)	*	**	*	**	**	*	*	*	*	**	*	*
Puxton Church Field	***	-	-	*	***	**	**	**	**	***	**	*
Vole Farm	***	*	***	***	***	***	***	***	***	**	***	*
Hardingworth	*	**	**	*	**	**	**	*	**	***	**	*
Lower Woods	**	-	***	*	**	***	*	**	**	-	*	**
Blackcliff Woods	*	*	***	*	*	*	*	*	**	***	*	*
Kirkdale North Meadow	*	*	***	*	*	*	*	*	*	*	*	*
Kirkdale South Meadow	**	**	**	*	***	*	**	*	**	***	*	**
Kinaleghin Priory	***	**	**	***	**	**	**	**	**	**	**	*
Score	22	10	21	17	25	14	14	16	-18	-21	-16	4
Fit	61%	28%	58%	47%	69%	39%	39%	44%	-50%	-58%	-44%	11%

The above table is further summarised in the following league table of individual factors as positive-indicators of human activity,

lead > phosphorus > magnetic susceptibility > loss on ignition > zinc > cadmium > copper > pH > manganese

and of generally negative-indicators of human activity,

cobalt > nickel > chromium

The next step is to consider the evidence for associations between factors.

Table 5.4 (Explanatory Notes)

The table illustrates the two clear groupings of correlated factors, those associating with phosphorus and carbon, and those associating with nickel and cobalt.

The factors shown in **bold** type are those most significantly correlated ($p = 0.001$).

Those factors shown in *italics* are significantly correlated to one (or some) of the other factors.

5.1.2 Associated Factors

A. STATISTICAL ANALYSIS

Statistical analysis of the data from different sites revealed significant correlations between certain soil factors (see Appendix 2 for individual site correlation-data). There is a clear linkage between certain elements (e.g. phosphorus and organic carbon, zinc and cadmium, and nickel and cobalt) almost certainly attributable to affinities in their soil chemistry. Some factors, such as manganese, copper, chromium and magnetic susceptibility were inconsistent (or at least appeared at times to be independent) in their associations. But most noticeable were two clear groupings which either focused on phosphorus and organic carbon, or on nickel and cobalt (see Table 5.4). By and large lead, copper, zinc, cadmium and magnetic susceptibility were most often associated with the former and chromium and manganese with the latter.

Table 5.4 Soil factor evaluation – Statistical Association (i.e. co-incidence with other soil factors as determined from correlation coefficients – for details see Appendix II on the accompanying CD)

Evaluation	Phosphorus Carbon Group	Nickel Cobalt Group
Shapwick Church Field 1996	**P + C + Pb + Zn + Cd** + *MS*	**Ni + Co + Cr + Mn + Cu**
Shapwick Church Field 1998	**P + C + Zn + Cd** + *Cu + MS*	**Ni + Co + Mn + Cu**
Shapwick Henry	**P + C**	**Ni + Co + Cr + Mn** + *Cu + Cd + Zn*
Shapwick Sladwick	**P + C + Zn** + *Co*	**Ni + Co + Mn + Cd** + *Cu*
Hamm Farm 50 metre	**P + C + Pb + Cu + Zn+ Cd**	**Ni + Co + Cr** + *MS*
Hamm Farm 20 metre North	**P + C + Pb + Zn + Cd** + *Cu*	**Ni + Co + Cr + Mn**
Hamm Farm 20 metre South	**P + C + Pb + Zn + Cd + Ni** + *Cu*	**Ni + Co + Cr**
Hamm Farm 10 metre Quadrant 1	**P + C + Pb + Cu + Zn + Cd**	**Ni + Co + Cr + Mn**
Hamm Farm 10 metre Quadrant 2	**P + C + Zn** + *Cd + Cu*	**Ni + Co + Cr + Mn**
Hamm Farm 10 metre Quadrant 3	**P + Cu + Zn + Cd**	**Ni + Co + Cr + Mn**
Hamm Farm 10 metre Quadrant 4	**P + C + Pb + Zn + Cd** + *Cu + Mn*	**Ni + Co + Cr**
Puxton Church Field	**P + Pb + Cu + Zn + Cd**	**Ni + Co + Cr + Mn**
Vole Farm	**P + C + Cu** + *Pb + Zn + Mn*	**Ni + Co + Cr** + *Mn*
Hardingworth	**P + C + Cd** + *Pb + Cu + Zn +MS*	**Ni + Co + Cr + Mn**
Lower Woods	**P + C** + *Pb + Cu + Zn + Cd + MS*	**Ni + Cr + Mn** + *Cu*
Blackcliff Woods	**P + C + Pb + Zn+ Cd** + *MS + Mn*	**Ni + Co + Cr** + *Mn*
Kirkdale North Meadow	**P + C + Pb + Zn + Cd** + *MS + Cu + Mn*	**Ni + Co + Cr + Mn**
Kirkdale South Meadow	**P + C + Zn + Cd + Mn + MS**	**Ni + Co + Cr**
Kinaleghin Priory	**P + C + MS** + *Zn + Cu + Cd*	**Ni + Co + Cr** + *Mn*

There is also a tendency for these two groups to be negatively correlated. This distinction is also evident in the isoline plots[70] as these statistical correlations are reflected in their geographical distribution. The phosphorus/carbon group is almost always associated with areas of confirmed past human activity, whereas the nickel/cobalt group is more pronounced away from these areas. For the purposes of further discussion, these soil factor associations are henceforth referred to as the hypothesised "anthropogenic" and "non-anthropogenic" groups, although, as will be seen, these convenient labels are not attached to hard and fast categories.

Hypothesised Anthropogenic Group:	**Phosphorus**	**Cadmium**
	Carbon[71]	**Copper**
	Lead	**Zinc**
Hypothesised Non-Anthropogenic Group:	**Nickel**	**Chromium**
	Cobalt	

Note: ***Magnetic Susceptibility*** has been omitted from the Anthropogenic Group even though is was often associated with settlement sites. This was done on the grounds that the approach to this piece of work was always intended to be geo-chemical and was decided to keep it so.

As has been indicated above this "divide" can be attributed to relative dilution.

B. DILUTION

Compared with the enhanced levels of phosphorus, lead, zinc, copper and cadmium in soils from settlement sites, it is tempting to attribute the apparently diminished levels of nickel and cobalt (often together with chromium) to a disparity in the presence of these elements in human activities. But food and fuel sources of nickel and lead, for example, are not dissimilar: nor too are those of cadmium and chromium (Table 2.2, page 31). Might we then turn to soil chemistry for an explanation? The displacement of metal cations in the soil is certainly affected by acidity (as is solubility) and ordered by the electro-mobility of the element in question. Variations in the field measurements of soil acidity have not, by and large, shown significant variability (see page 197).

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[70]Isoline plots of the data from different sites revealed clear spatial associations between certain soil factors largely but not entirely in accordance with statistical associations. Occasionally the division between "anthropogenic" and "non-anthropogenic" soil factors breaks down entirely in what have been labelled "hotspots". These anomalies are discussed in the next section.

[71] For the purposes of this investigation "carbon" is defined as that fraction of the soil measured by the loss on ignition methodology described on page 121.

Nickel and cobalt have a greater soil stability than either zinc or cadmium (see Part 2, page 74). Therefore, disparities in the sources or in the rate of loss from the soil of the tested elements do not provide adequate explanations for the "dilution effect" witnessed at most of the sites (see Figure 5.11).

The solution lies in the comparative rates of element deposition in relation to the pre-existing soil composition. The following set of calculations are based on the data presented Table 2.18 & 2.19 which pertain to a hypothetical family occupying a fixed area over a set number of years (see Part 2, page 49) A simplified version of the table is reproduced here as Tables 5.5 & 5.6.

Table 5.5 Input and enrichment values for soils based on input from human faeces. Calculations are based on the input of a family of 10 persons over a period of 100 years affecting an area of soil of 10 x 10 metres to a depth of 5 cm (using a bulk density of 1.3g/cm^3).

Element	*Faeces input g*	*Normal soil mg/kg*	*Enrichment mg/kg soil*	*Enrichment % Normal soil*	*Effect*
Cadmium	18.25	0.35	2.8	800	enrichment
Chromium	29.2	70	4.5	6.4	dilution
Cobalt	32.85	8	5.1	64	dilution
Copper	1241	30	190.9	636	enrichment
Lead	109.5	10	16.9	169	enrichment
Manganese	1314	500	202	40.4	dilution
Nickel	135	50	20.8	41.6	dilution
Zinc	4020	90	618.5	687	enrichment
Phosphorus	182500	650	28077	4319	enrichment
TOTAL	189444	1408.35	29149	-	

Table 5.6 Input and enrichment values for soils based on input from wood ash. Calculations are based on the input of a family of 10 persons over a period of 100 years affecting an area of soil of 10 x 10 metres to a depth of 5 cm (using a bulk density of 1.3g/cm^3).

Element	*Wood mg/kg (mean values)*	*Normal Soil mg/kg*	*Enrichment mg/kg soil*	*Enrichment % Normal Soil*	*Effect*
Cadmium	0.25	0.35	1.92	549	enrichment
Chromium	0.5	70	3.85	6	dilution
Cobalt	0.1	8	0.77	10	dilution
Copper	9	30	69.2	230	enrichment
Lead	1	10	7.69	77	dilution
Manganese	250	500	1923	385	enrichment
Nickel	1	50	7.69	15	dilution
Zinc	40	90	307.7	342	enrichment
Phosphorus	400	650	153846	23669	enrichment

Worked example:

Using the data from the above Table 5.5, a kilogram of "normal" soil from the site prior to settlement would have contained 1.41 g (1408.35 mg) of the elements under consideration. After 100 years these elements would have been enriched by 29.149 g. i.e. an enrichment factor of 20.6 (29.149 divided by 1.41). A kilogram of soil would now contain the equivalent of 29.149 g of "enriched" soil and 970.851 g of the "normal" soil.

If we now take an individual element, **nickel** for example, prior to settlement one kilogram of soil contained 50 mg of the metal. After 100 years a kilogram of soil would contain

971 g "normal" soil containing (@ 50 mg per kg) 48.6 mg of nickel

29 g "enriched" soil containing (@ 20.8 mg per kg) 0.6 mg of nickel

After 100 years of occupation on this hypothetical site 1 kg of soil would contain 49.2 mg of nickel. I.e. the nickel content of 1 kg of soil after 100 years of occupation would have *apparently* **fallen** by 1.6 % from 50 mg per kg to 49.2 mg per kg.

If this calculation is repeated for **lead,** for example, a kilogram of soil after 100 years would contain

971 g "normal" soil containing (@ 10 mg per kg) 9.71 mg of lead

29 g "enriched" soil containing (@ 16.9 mg per kg) 0.49 mg of lead

In other words the lead content of 1 kg of soil after 100 years of occupation would have *apparently* **risen** by 2.0 % from 10 mg per kg to 10.2 mg per kg.

If these calculations are applied to the remaining elements the so-called "anthropogenic" and "non-anthropogenic" groups become apparent (see Table 5.7). Indeed what is happening is no more than the more prolific residues squeezing out (per unit of soil weight) , that is ***diluting*** those elements deposited in smaller quantities relative to their background abundance[72].

Table 5.7 Apparent soil "enrichment" and "dilution" by elements derived from human faeces.

Element	*Enrichment*	*Element*	*Dilution*
Phosphorus	+ 122.4%	Chromium	- 2.7%
Copper	+ 25%	Nickel	- 1.7%
Cadmium	+ 20%	Cobalt	- 1.05%
Zinc	+ 9.3%		
Lead	+ 2.0%		
Manganese	+ 0.17%		

[72] It is assumed for the purposes of calculation that anthropogenic residues were deposited long enough ago for the organic components to have decomposed into stable state and that the density of the soils in and surrounding ("enriched" and "normal") the focus of activity to be more or less the same.

It is interesting if these forms of calculation are applied to the residues contained within wood ash (see Table 5.8).

Table 5.8 Apparent soil "enrichment" and "dilution" by elements derived from wood ash.

Element	*Enrichment*	*Element*	*Dilution*
Phosphorus	+ 3,677%	Chromium	- 14.7%
Cadmium	+ 50%	Cobalt	- 14.1%
Manganese	+ 44.4%	Nickel	- 13.2%
Zinc	+ 37.1%	Lead	- 5.4%
Copper	+ 0.20.4%		

The same groupings appear with one significant exception. Per unit weight of soil, lead residues derived solely from wood ash would be diluted over time by other elements, particularly by phosphorus.

It can be seen that the hypothesised groupings of "anthropogenic" elements, that is those frequently found closely associated with sites of past human activity (for this study taken as phosphorus, lead, copper, zinc, cadmium, as well as carbon as measured by loss on ignition) and "non-anthropogenic" elements, those frequently disassociated with sites of past human activity (nickel, cobalt and chromium) are largely the artefacts of competitive deposition. The term "non-anthropogenic" has been applied as a convenience but is, it would seem, a misnomer. Perhaps "site-related" and "non-site related" would have been better, but since the application of reciprocal values of "non-anthropogenic" elements has proved as good an indicator as some "anthropogenic" elements (see Figures 5.9 I & J) even this notation is not satisfactory. It was decided to retain the original terms for the groupings subject to the above cautionary notes.

C. THE BEHAVIOUR OF LEAD

Lead residues derived from wood ash would not appear to be good indicators of ancient settlements. Even the enhancements from faeces are modest (see Tables 5.5 & 5.6). Yet lead has proved in this study to have been a better indicator than phosphorus and indeed than any other single element. It might be speculated that lead residues originate from sources other than human faeces and wood ash and indeed such sources are discussed later. However, it is quite possible that the data above, based on modern diets (Snyder et al, 1975) significantly underestimate the faecal-lead content that may have existed when lead, lead alloys, lead oxides and lead salts were far more widely and much less discriminately used than they are today. (See also page 36).

Notes for the facing page

Calculation of additive values:

Additive values were arrived at by subtraction of the overall mean from each factor value and dividing the remainder by the standard deviation. These "standardised" data for each factor were added together and the mean calculated. This procedure has the effect of "normalising" the data so that differences in magnitude of the original data are eliminated.

Table 5.9 (Explanatory Notes)

In this table the full 19 **evaluations** from the 12 sites are presented and are listed in the first column. The second column, **site prediction**, is a subjective assessment (see scoring below) of how well the location of enhanced concentrations of hypothesised "anthropogenic group" of chemical elements (lead, phosphorus, loss on ignition, zinc, cadmium and copper) matches that of the archaeology. The third column subjectively assesses the performance of **phosphorus** alone as a site predictor so that it might be compared against a multi-element approach. The fourth and fifth columns assess how well statistically similar factors or "clusters" (derived from cluster analysis) match the hypothesised **"anthropogenic"** and **"non-anthropogenic"** (nickel, cobalt and chromium) groups.

Scoring:

Fit with the archaeology	Score
very good	3
good	2
fair to good	1.5
fair	1
poor	0

Maximum score for the 19 evaluations is 57

Fit is calculated as a percentage of the maximum score.

Site prediction using the **hypothesised group of anthropogenic factors** gives an overall 61% fit. Note, however, that in only 2 evaluations was site recognition poor and in 12 out of 19 evaluations site recognition was good or very good. Using **phosphorus alone** as a site indicator only 9 out of 19 evaluations gave good or very good predictions.

5.2 THE USE OF COMBINED SOIL FACTORS

A method was sought to combine the measurements of associated soil factors in a way that would provide a composite picture of "anthropogenic" or "non-anthropogenic" evidence. A simple calculation (see facing page) provided additive values so that the combined data could be plotted as isoline maps. The hypothesised groupings were also compared with statistically correlated groupings as revealed by cluster analysis[73]. The following table (Table 5.9) summarises (a) how well the hypothesised groups predicted sites of past human activity; (b) how well cluster analysis (see Part 3, page 129) bore out these hypothesised groups; and (c) the comparative success of simply analysing the soil for phosphorus (see also the Explanatory Notes on the facing page).

Table 5.9 Site identification using combined "anthropogenic" data and phosphorus alone. A comparison is made with hypothesised groups.

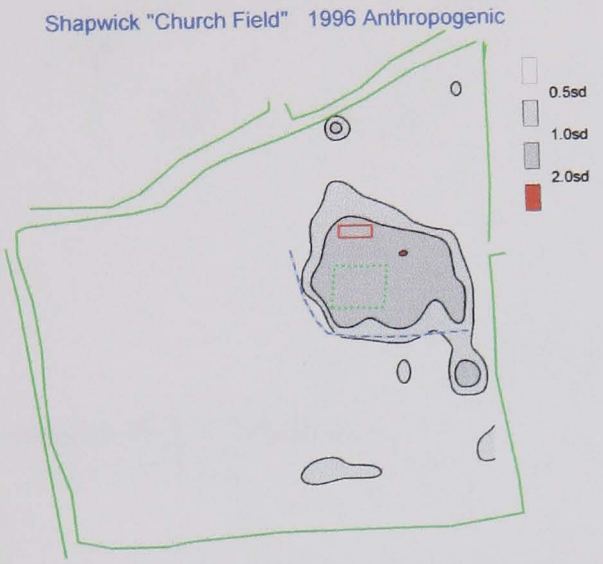
Evaluation	Site Prediction	Phosphorus alone	Recognition of hypothesised groups by cluster analysis	
			Anthropogenic	Non-anthropogenic
Shapwick Church Field 1996	very good	very good	fair	fair
Shapwick Church Field 1998	good	very good	poor	poor
Shapwick Henry	poor	fair	poor	poor
Shapwick Sladwick	poor	poor	poor	poor
Hamm Farm 50 metre	fair to good	fair to good	good	good
Hamm Farm 20 metre North	good	fair	good	good
Hamm Farm 20 metre South	good	good	fair	good
Hamm Farm 10 metre Quadrant 1	good	fair	good	good
Hamm Farm 10 metre Quadrant 2	good	fair	fair	good
Hamm Farm 10 metre Quadrant 3	fair	poor	fair	good
Hamm Farm 10 metre Quadrant 4	fair	fair	good	good
Puxton Church Field	very good	good	fair	good
Vole Farm	very good	good	fair	good
Hardingworth	very good	good	poor	good
Lower Woods	good	good	poor	poor
Blackcliff Woods	good	good	very good	very good
Kirkdale North Meadow	fair	fair	fair	fair
Kirkdale South Meadow	fair to good	fair to good	fair	fair
Kinaleghin Priory	very good	very good	fair	good
Score (see Explanatory Notes)	35	30	20	28
Fit	**61%**	**53%**	**35%**	**49%**

[73] The application of cluster analysis is discussed on page 129 in Part 3.

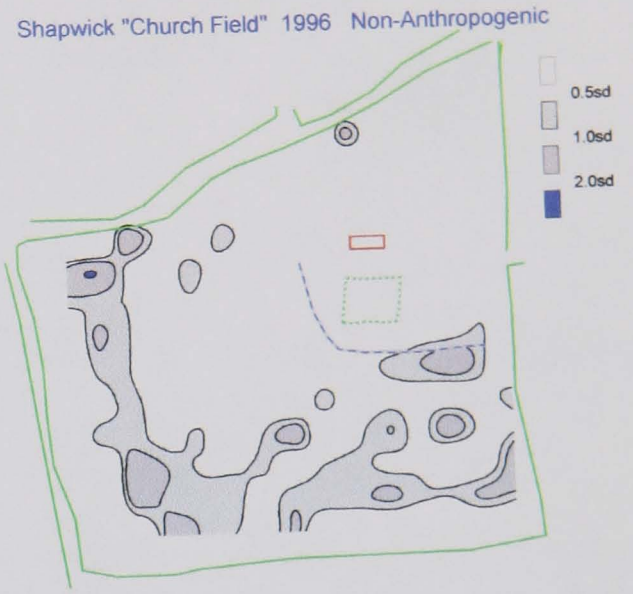
Isoline maps based on the hypothesised groups demonstrated good or very good association ("anthropogenic" factors) or disassociation ("non-anthropogenic" factors) with known archaeological evidence for most (12/19) evaluations and are, perhaps, most clearly evident at Church Field, Shapwick; Puxton and Vole (See Figure 5.11).

Figure 5.11 "Anthropogenic" and "Non-anthropogenic" Isoline Maps

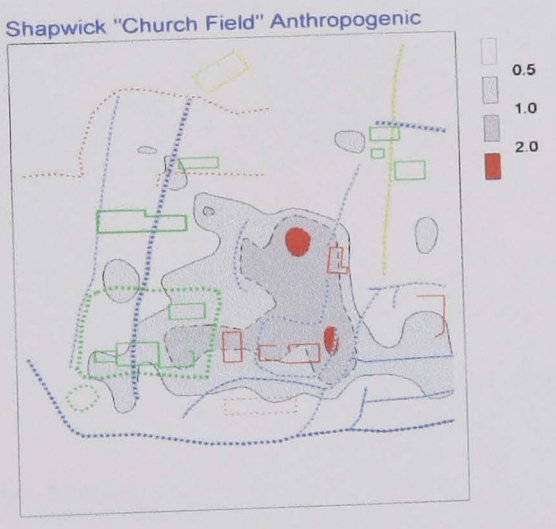
A. Site 1a (page 135)



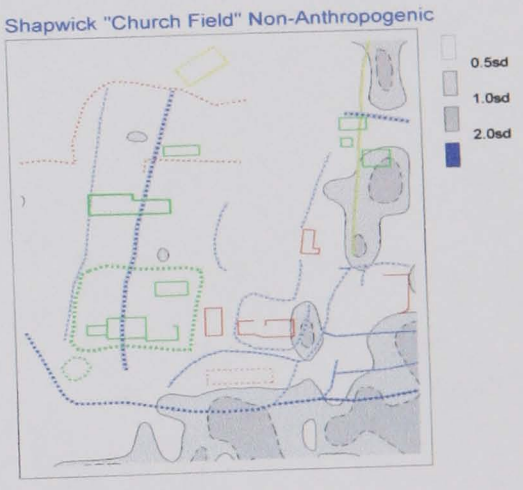
B. Site 1a (page 135)



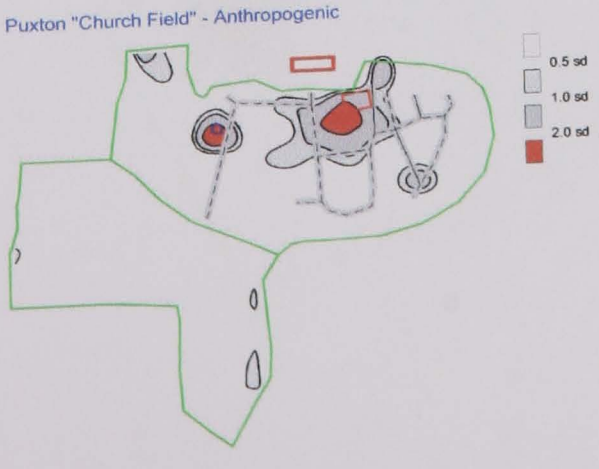
C. Site 1b (page 135)



D. Site 1b (page 135)



E. Site 5 (page 156)



F. Site 5 (page 156)

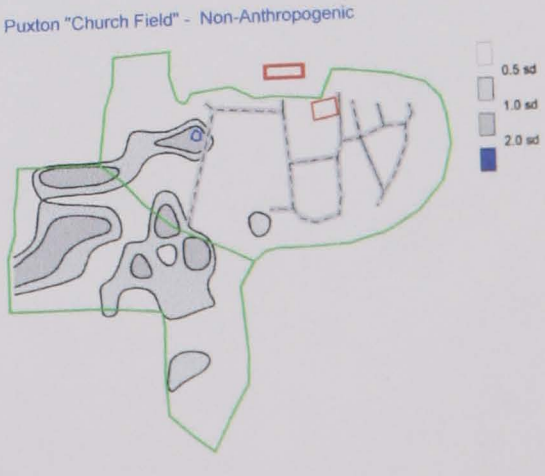
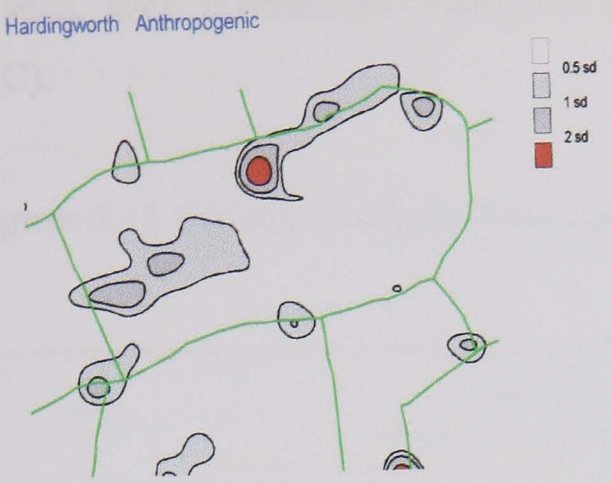
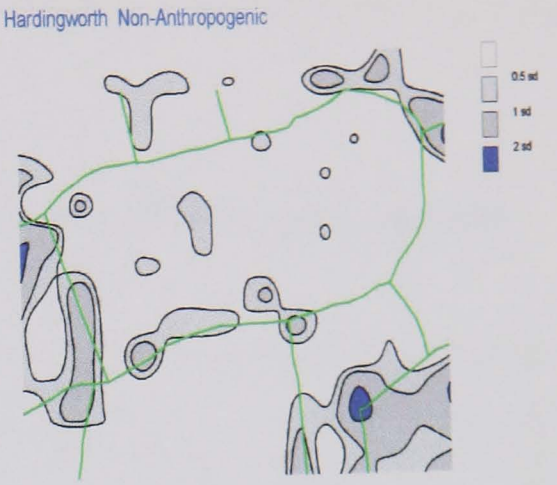


Figure 5.11 (Continued) "Anthropogenic" and "Non-anthropogenic" Isoline Maps

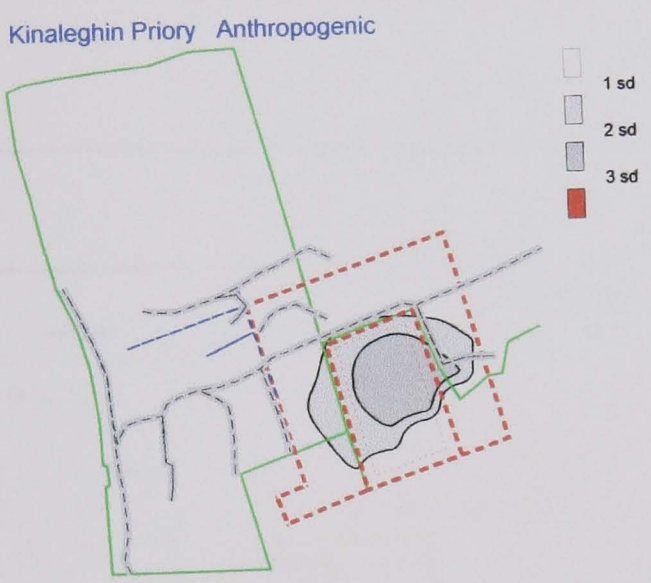
G. Site 7 (page 163)



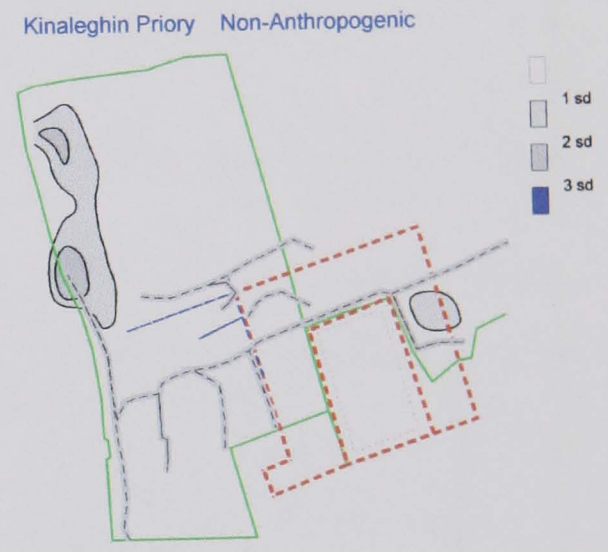
H. Site 7 (page 163)



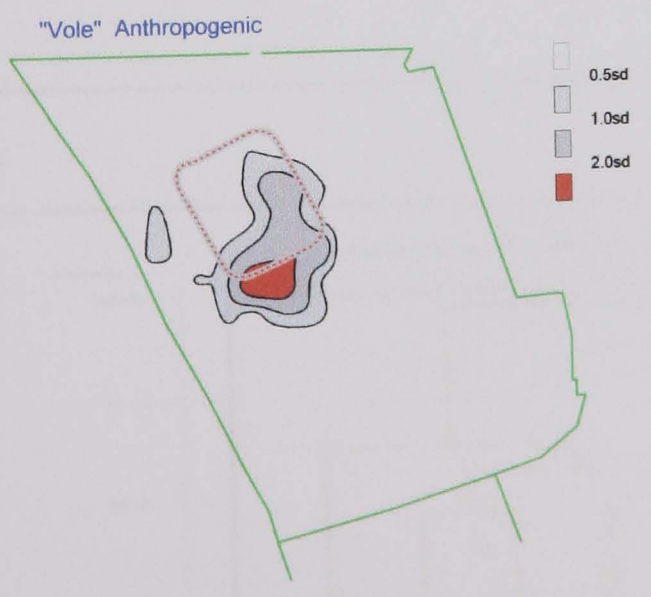
I. Site 12 (page 178)



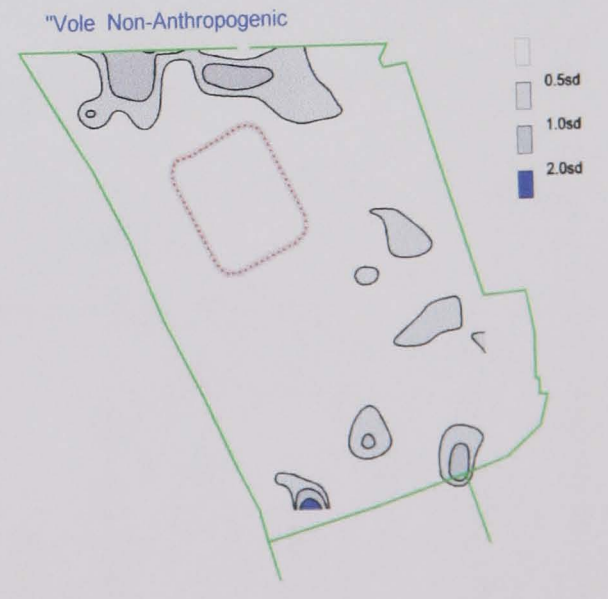
J. Site 12 (page 178)



K. Site 6 (page 160)



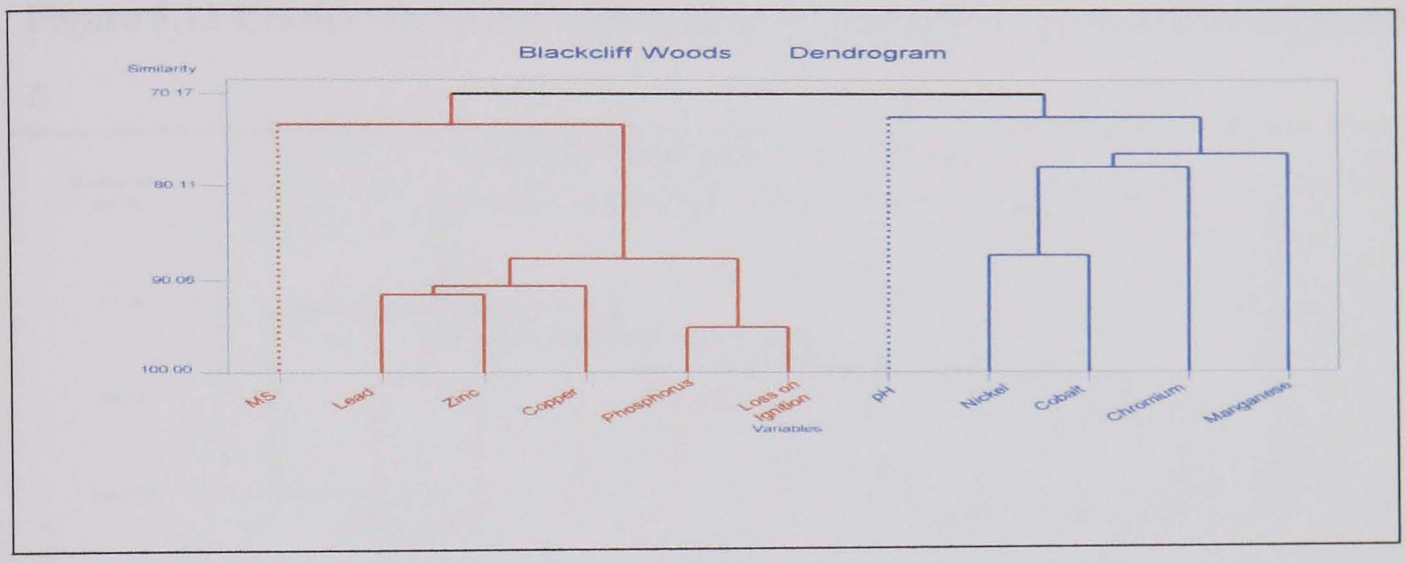
L. Site 6 (page 160)



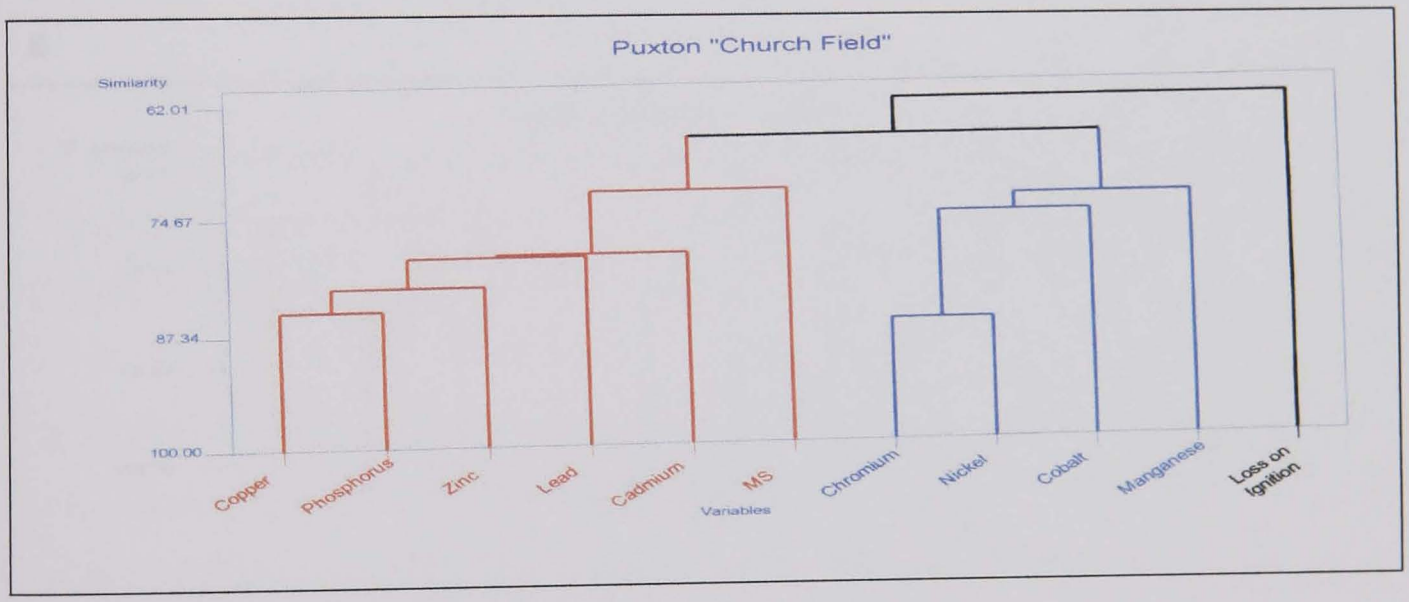
Cluster analysis dendrograms (see Part 3, page 128) did bear out the hypothesised "anthropogenic" and non-anthropogenic" groupings, to some degree at least, at a number of sites, such as Blackcliff Wood, Puxton, Vole and Hamm Farm (see Figures 5.12 A, B & C).

Figure 5.12 Cluster Analysis Dendrograms supportive of hypothesised groups

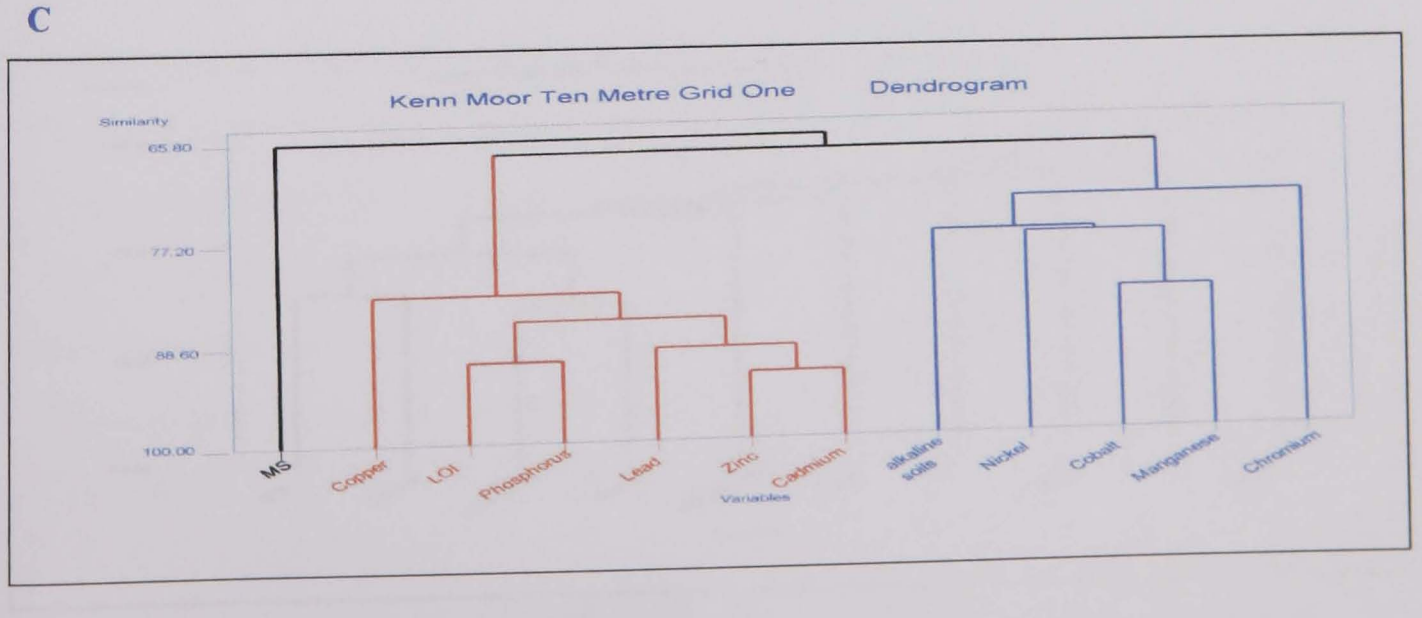
A



B



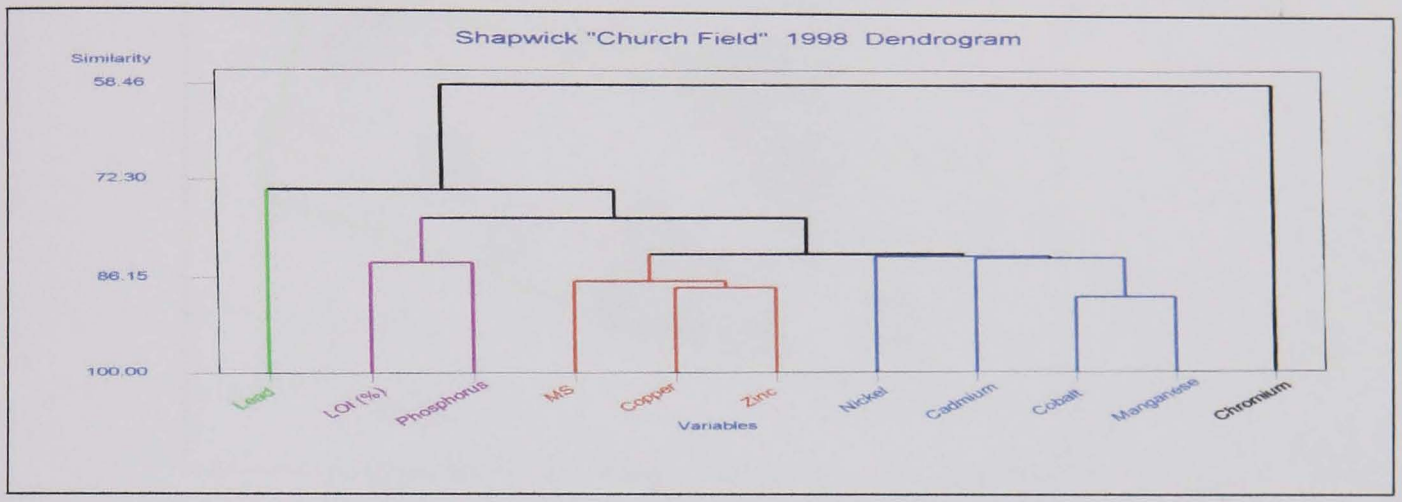
C



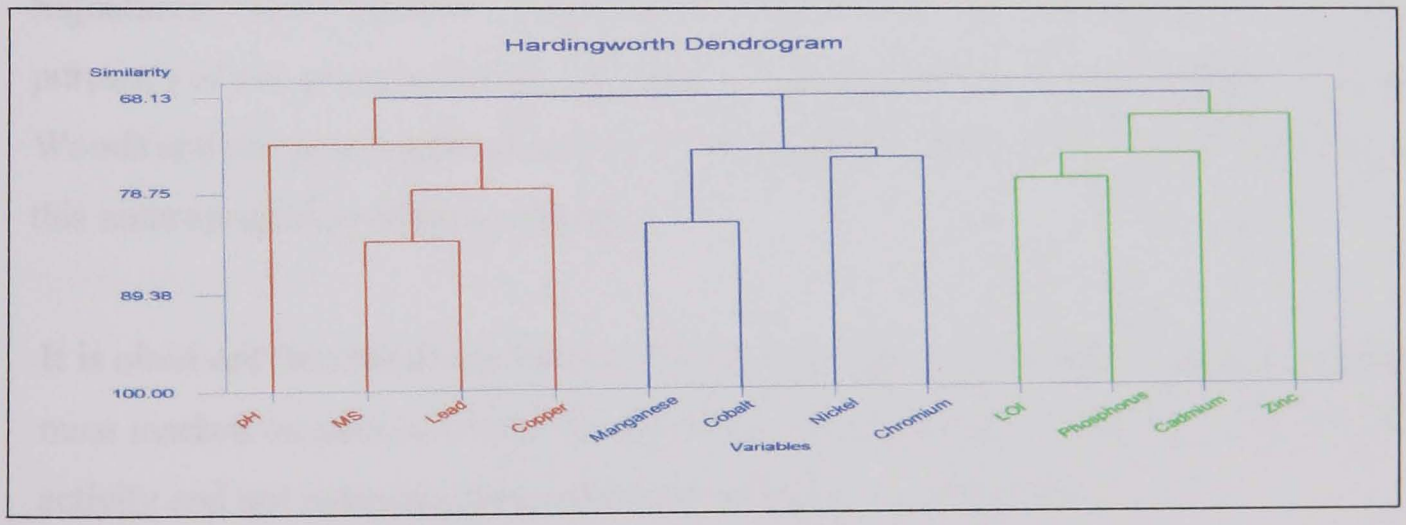
More often than not cluster analysis failed to confirm the postulated "anthropogenic" groupings (35%) being somewhat better for "non-anthropogenic" factors (49%). This failing is amply demonstrated at Shapwick "Church Field" in 1998, at Hardingworth and Lower Woods where cluster analyses showed poor recognition of the hypothesised "anthropogenic group" (See Figure 5.13) but isoline maps gave a good or excellent fit with the loci of human activity (See Figure 5.11 C & G and 5.14).

Figure 5.13 Cluster Analysis Dendrograms not supportive of hypothesised groups

A

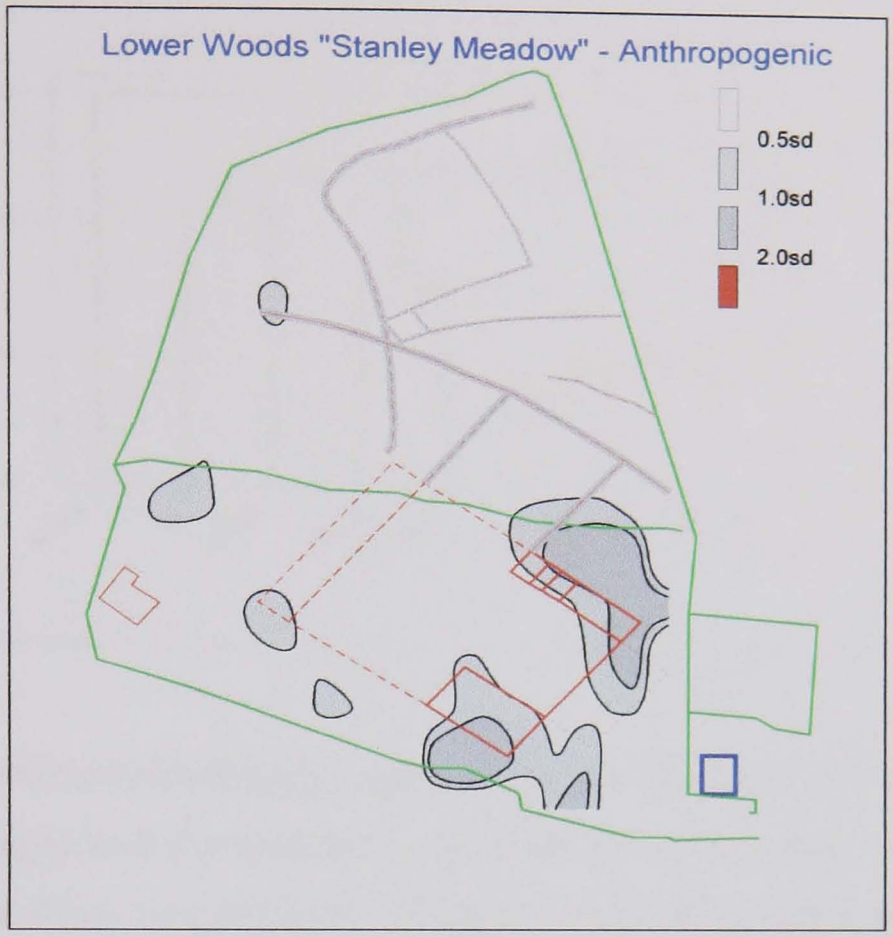


B



C

Figure 5.14 **Lower Woods "Anthropogenic" Isoline Map** (Site 8, Page 165)

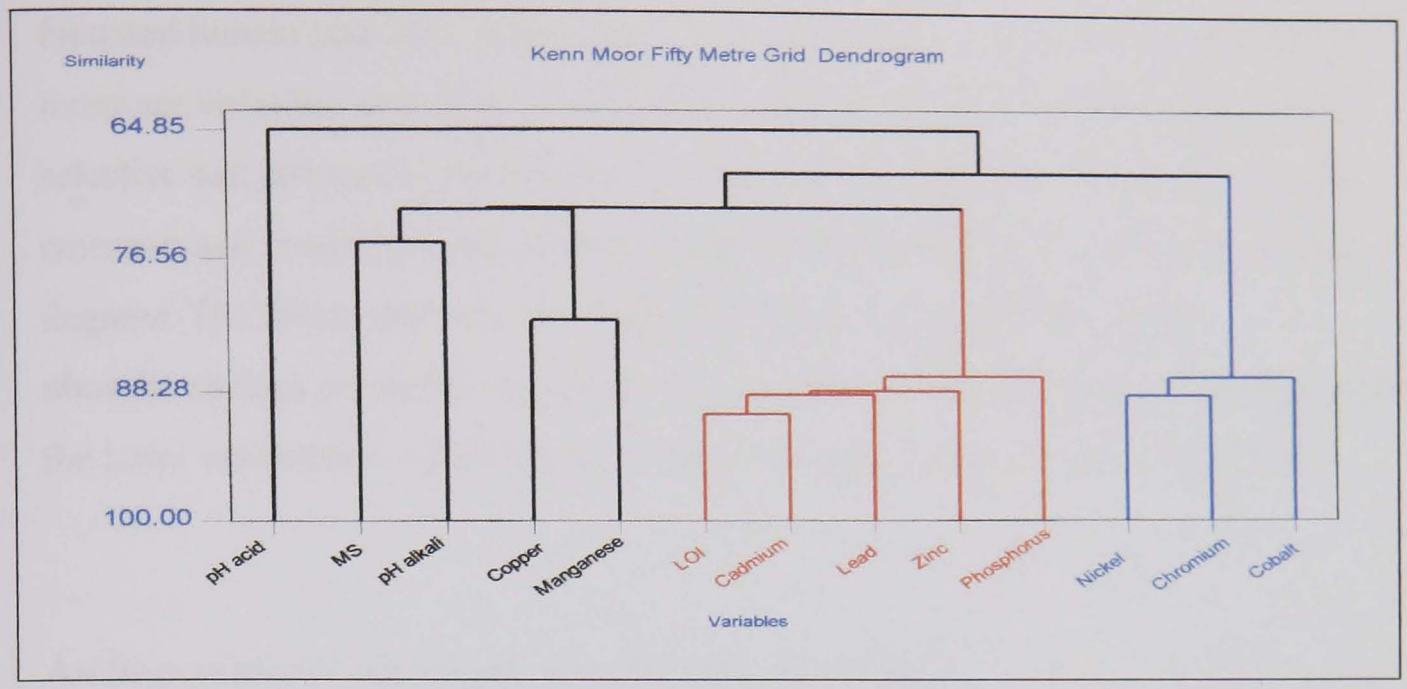


This is not to dismiss contour analysis as a useful tool in site diagnosis (see Type Signatures below) but rather to testify the robustness of the "anthropogenic group" for purposes of site prospection. In this piece of research both the Roman building at Lower Woods and the post-medieval debris spread at Hardingworth were located solely by using this anthropogenic-grouping technique.

It is observed that the disassociation of cluster groups with the hypothesised groupings is most marked on sites in which the survey has been contained within the zone of human activity and not extending beyond it into relatively undisturbed areas.

It is suggested that the closer a survey focuses on the centre of past activity, so the "anthropogenic" – "non-anthropogenic" divide becomes blurred or obscured entirely. This in itself reinforces the case for the broader survey which provides a relatively neutral context in which the evidence of human disturbance sits. There is a corollary to this. In too wide an ambit, the focus of human activity (as demonstrated by correlating soil factors) may also becomes less clear. This can seen in the cluster analysis dendrogram for Kenn Moor in the 60 ha survey (see Figure 5.15).

Figure 5.15 Cluster Analysis Dendrograms for Kenn Moor Fifty Metre Survey



Cluster analysis occasionally suggested that, on individual sites, other combinations of factors might be better indicators of past activity (for example See Figure 5.13 D). However, the groups of factors statistically associated by cluster analysis were not necessarily observed to be in close spatial association in the field, and *vice versa*. Some attempt should be made to explain this.

The statistical analysis of data compares populations (e.g. the respective concentrations of nickel and cobalt in each and all of the samples) and determines if they behave in a similar way. If they are correlated or "clustered" it would be reasonable to assume they are linked by some common factor.

Examination of isoline maps for different factors on particular sites show, on close examination, that even when an overall geographical association is clear, the spatial distribution of individual values is rarely a perfect match and that the peaks of concentration are often somewhat offset. In the case of phosphorus and loss on ignition, or of nickel and cobalt the match is, in most cases, pretty close. But it is less so for other metals and, for the "anthropogenic" and "non-anthropogenic" groups, there is a consistent mismatch.

There could be several explanations for this behaviour and the following two are suggested. First, these factors could be generated by different human activities or from different sources. The manure heap, the midden, floor sweepings, kiln ash, fallen

daub walls, all of these may produce disparate amounts of a range of accumulating soil residues but are closely associated simply because they are the result of geographically focussed human activities. Alternatively, all these factors could be common residues of many activities but over time become chemically sorted through the competitive or selective soil processes which come into play thus maintaining those factors with a common and compatible soil chemistry and diluting or displacing others to varying degrees. The disassociation, both statistically and geographically, of the phosphorus/loss on ignition group and the nickel/cobalt group supports, in my opinion, the latter explanation, although the effects of human behaviour are not dismissed.

An improvement on simple phosphorus evaluation?

Finally, a criticism often levelled at the multi-factor approach has been the claim that it reveals nothing that cannot be determined by simple phosphorus analysis. This has clearly been shown not to be the case. Analysing the soil for a range of indicators improved the chances of site recognition from 53% to 61% (see Table 5.9 on page 227). This improved detection has the bonus in that the additional information increases interpretive potential (see Type Signatures below).

5.3 THE EVIDENCE FOR TYPE SIGNATURES

Apart from the use of soil analysis to locate the focus or extent of past human activities, it would be useful if associations, or relative concentrations, of soil factors threw some light on the activities themselves. One of the objectives of this thesis was to determine if soil analysis could identify period- or process-related "type signatures". In the event only a minimal amount of follow-up investigation was possible and many "interesting" anomalies remain unresolved.

Notwithstanding, site-specific correlation of certain soil factors has been demonstrated both statistically and geographically. However, these methods were not always complementary. Nevertheless, it is important to consider all and every form of factor association if the potential for type signatures is to be investigated and the following observations are offered.

These can be summarised as follows:

5.3.1 Multi soil-factor concentrations ("hotspots")

There are small loci where peaks in both anthropogenic and non-anthropogenic factors coincide. These "hotspots" have already been mentioned above and the clearest example was recorded in Puxton "Church Field" (See Figures 5.11 E & F) where they coincided with a small circular depression. It has been suggested that this was a storage pit that has been backfilled with a variety of debris (Rippon, pers. com.). However, there were medieval clay pits in the North Meadow at Kirkdale that had been similarly back-filled but these were not prominent features on the isoline maps.

5.3.2 Single soil-factor concentrations

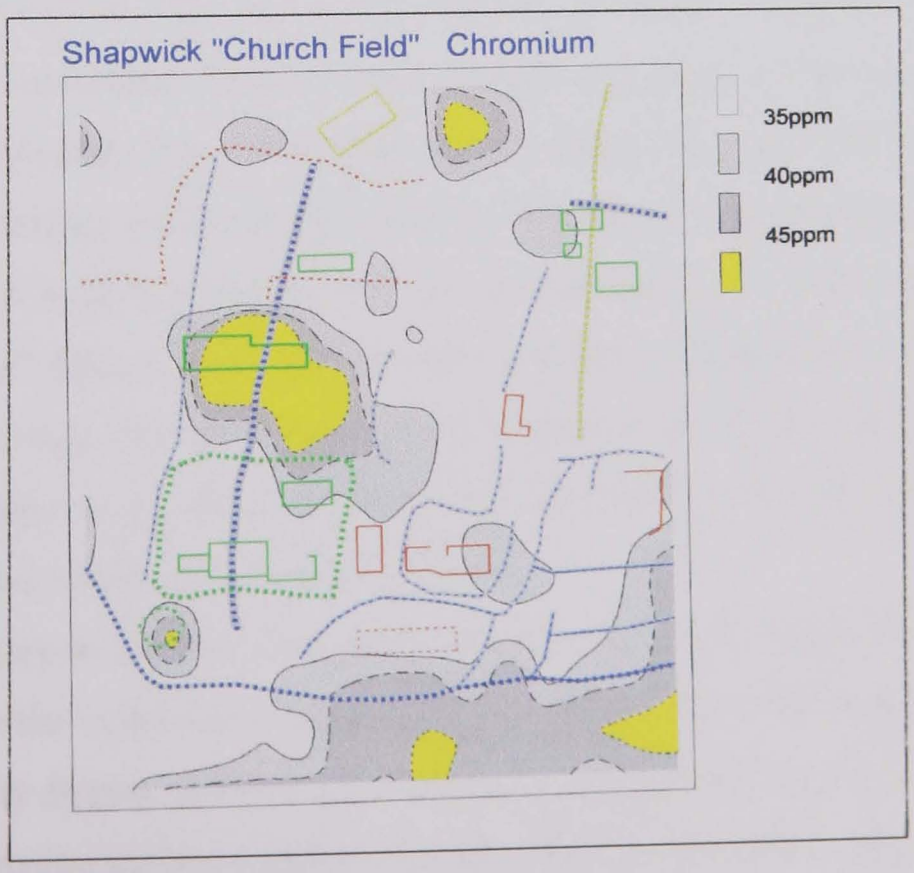
The concentration of **lead** around the site of the old church in Shapwick "Church Field" (See Figure 5.6 A & B) was not matched, as is usually the case, by similar concentrations in phosphorus (Figure 5.1 A & B) or organic carbon (Figure 5.4 A & B)

(as was the other lead patch to the east), or indeed by other soil factors (except chromium – but see below). It has already been suggested that the frequency with which pieces of bone are found in these black soils around the church that the high lead count could be attributable to cumulative residues from inhumations. It is interesting to note that the patches of soil heavily enhanced by lead in Sladwick field (See Figure 5.6 C), although accompanied by enrichments in other heavy metals, were also lacking the usual peaks in phosphorus (Figure 5.1 C) and organic carbon (Figure 5.4 C). No significant number of bone fragments were found here.

Soil analysis revealed a band of **copper**-enriched soil 20m wide and 100m long aligned with buried ditches on the suspected Roman settlement Hamm Farm (See Figure 5.8 I). This strip was also measurably more alkaline than the adjacent soils. This could represent some form of ditch infill (as seen at Hardingworth) or track metalling. At Hardingworth the (relatively modern) ditch infill was also copper-rich (See Figure 5.8 G) and alkaline (Figure 5.5 C) but soils had in addition high levels of lead and magnetic susceptibility(Figure 5.6 E and 5.3 E). Interestingly, the ditch infill at Hardingworth was also statistically distinct (see cluster analysis dendrogram 5.13 B) from other anthropogenic soil assemblages.

The central patch of **chromium**-rich soils measured by the 1998 five metre survey at Shapwick "Church Field" was anomalous (see Figure 5.16).

Figure 5.16 Shapwick "Church Field" Chromium (Site 1b, Page 135)



Unlike its usual non-anthropogenic behaviour, soil chromium was elevated in the area of the old church and closely associated with a mound of Roman masonry debris. Could this be evidence of painted wall plaster residues, as chrome based paints were used both during the Roman and medieval period?

To the north east of Kirkdale North Meadow there is a small peak of **magnetically susceptible** soils (see Figure 5.3 O) which has been associated with the location of the annual Boy Scout's bonfire (Rahtz, pers. com.). This enhancement stands alone in the medieval "washout" area and it not associated with any other soil factor. Soils from the charcoal bed at the Blackcliff Wood settlement and the site of the possible bonfire of grubbed orchard trees at Henry also had high magnetic susceptibility readings (see Figures 5.3 M and 5.2 D) but also were rich in organic carbon, phosphorus and lead. Possibly the Boy Scout's bonfire is not what it seems or the very recentness of the fire has mitigated against any significant accumulations of soil chemical residues.

5.3.3 Geological considerations:

Variations in the relative abundance of soil factors need not, of course, be solely attributable to human activity. The identification of non-human influence is important so that it can be taken into account in any settlement evaluation. This is particularly so in larger multi-field surveys where changes in geology and soil type are more likely to be encountered. The Hamm Farm survey covered an area of 60 hectares, the south-western half of which lies on a ridge of Triassic silty mudstones and thin sandstones beneath a layer of recent marine clays and alluvial silts. To the north east, this Triassic "bedrock" dips under deeper alluvium towards the peat filled basin of Kenn Moor. It is not surprising, therefore, that the wetter lands in the north-eastern half of the survey area support relatively undisturbed pastures in which the archaeology and the associated residues are better preserved.

A corollary to the bias of better preservation is a bias of poor survival. The soils that make up the collection of fields known as "Henry" are particularly shallow and overlie the gently dipping scarp edges of thin layers of Liassic clays and limestones. This active erosion surface generates its own mineral enrichment of the soil making the search for anthropogenic residues more difficult.

Finally, a cautionary note on recent alluvial deposits. These can cover the site of past settlement or activity to a depth that will be beyond the activity of some or most of the re-distributive flora and fauna. Anthropogenic evidence in the surface soil may be limited as a result. This was not a problem on Hamm Farm where alluvial deposits are relatively shallow, but in southern Somerset these deposits can be several metres thick. At Kirkdale the more recent riverine deposits bordering the beck were, as has been mentioned above, richer in copper and this has been attributed to river-borne material derived from mineral workings some miles up stream.

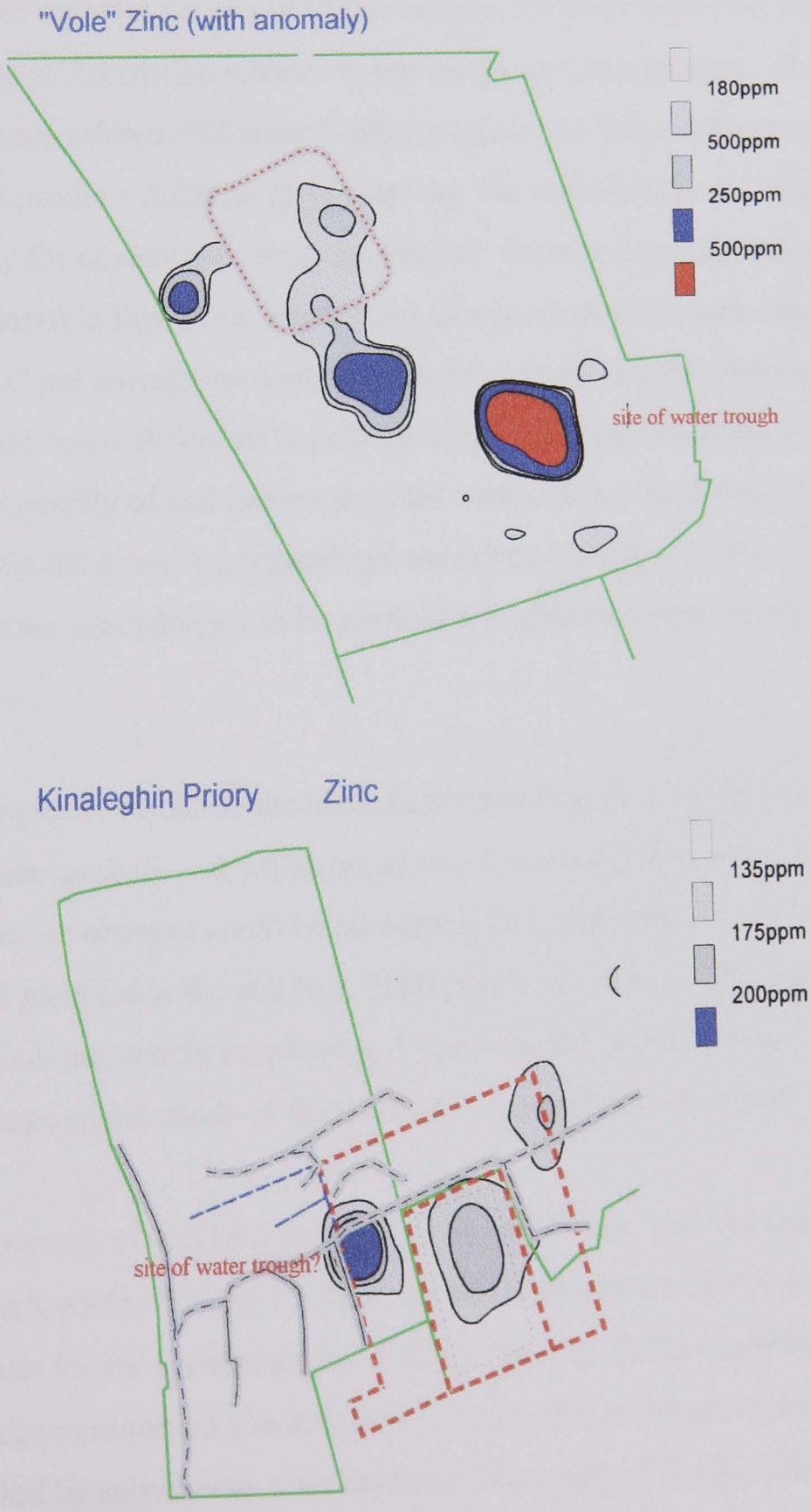
5.3.4 Agronomic considerations:

Geological variation is not the only landscape effect that needs consideration when interpreting soil analysis results. There are also the effects of wider agricultural practices. The distortions caused by contrasting application of arable (regularly cultivated) and grassland farming has been mentioned above. Farmland drainage is another consideration. Poorly drained land will support a different soil chemistry to that which is freely draining and can allow a longer survival of organic material. It has been postulated above (see page 193 ... also page 62 in Part 2.4.1) that the survival of some organic forms of carbon could be important for the survival of other anthropogenic residues. Proximity of sites to rivers, dykes and rhynes is likewise an important consideration where, not only a higher water table and the effects of flooding, but also the deliberate dredging and dumping of silt will alter the balance of critical residues. This was particularly clear along the banks of the Little River to the south of Hamm Farm (see Figure 5.4 F). Woodland edges can influence soil water retention, sometimes keeping soils moist by increasing local humidity and reducing evaporation; sometimes drying the soil out through root action. The presence of trees can understandably effect the level of organic matter through cumulative autumn leaf falls and even indirectly by providing shelter for livestock where dunging will be more intense – the high phosphorus levels at the east end of Hardingworth (see Figure 5.1.E) were under the only tree shelter in the field and where cattle were seen to congregate frequently.

Another livestock associated source of soil contamination is the siting of galvanised (zinc-rich) water troughs and hay racks. Very localised and exceptionally high elevations in soil zinc concentrations were recorded at Kinaleghin and Vole (see Figures 5.17)

Figure 5.17 Zinc anomalies associated with galvanised farm equipment

(Site 6, Page 160 and Site 12, Page 178)



5.3.5 The potential for type signatures

It has been demonstrated that some soil factors, such as phosphorus & loss on ignition and nickel & cobalt, are closely correlated; that certain groups of soil factors form almost predictable relationships with sites of human activity, described in this thesis as "anthropogenic" or "non-anthropogenic"; and that some soil factors are much less predictable in their associations, such as manganese. In the discussion on soil "dilution" (see page 223), it became evident that increases or decreases in the concentration per unit weight of soil of the various elements depended on the comparative rate of deposition relative to the background abundance. This relationship was clearly process-related. Different "anthropogenic" or "non-anthropogenic" groupings[74] can produce different groupings and the identification of these offers the best opportunity for developing "type signatures". Among the data manipulation techniques explored in this thesis which have shown some promise in recognising "type signatures" are correlation analysis, cluster analysis and the plotting of composite isoline maps. A further hopeful feature of the above studies was the observed heterogeneity of soil factors revealed under closer examination. This variability, within the broader geographical association, suggests there is scope for different soil-factor assemblages to be attributed to different taphonomies even in a small area.

A useful development would be the identification of a neutral soil factor that is not affected by human activity and which could provide an unchangeable standard and against which other changes could be measured. One suggestion is Titanium which is both stable and plentiful in the soil (e.g. 5000 ppm - see Table 2.32, page 69) but, more importantly, is comparatively scarce (e.g. 1 ppm) in plants and unlikely to demonstrate soil enhancements as the result of faeces, urine or wood ash accumulation.

Large concentrations of soil factors found to be coincident with the archaeology are "signed up" fairly easily, but can the finer details of soil-factor distribution provide an interpretive basis for the archaeologist? The question is, do the observed patterns of soil residues relate entirely to the activities or processes which generated them, or have they been altered by subsequent soil chemistry? The answer to this dilemma, if one

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[74] The terms "anthropogenic" or "non-anthropogenic" are not appropriate labels but have been, nonetheless, adopted – see page 213.

exists, depends on the accumulation of an extensive data base derived from the archaeological investigation of each and every soil anomaly as it arises and/or the chemical analysis of soils associated with specific past activities identified by archaeological investigation.

In the event, the investigation of process-related type signatures was limited in this study but, nevertheless, some foundations have been laid for future work. Any continuation of the research presented here would need to follow that line.

5.3.6 "Time signatures"

Some of the soil residues identified in the research could be attributed to a roughly datable origin and this lays a foundation, at least, for the identification of period-related activities which, hereinafter, are referred to as "time signatures".

It is evident that recent events such as bonfires, charcoal beds and the placing out of galvanised farm equipment can generate very strong signals. It is therefore important that such anomalously high readings should be carefully investigated before attributing them to a more ancient origin. What is also evident is that activity-indicative soil factors do not just fade away over time. Activities, that clearly ended hundreds if not a thousand or more years ago, still leave strong signals in the soil. This is well illustrated by the Roman settlements at Shapwick and Lower Woods (see Figures 5.6 C, 5.11 A & C, and 5.14) and the medieval settlements at Puxton and Vole (see Figures 5.11 E & K). It is reasonable to assume that the strength of these signals relates not only to the activity itself but also to the duration of that activity.

Strong signals in single elements, such as lead at the Lower Woods villa site (see Figure 5.6 Q) and (relative to the rest of the field) the Roman building or buildings in Sladwick (see Figure 5.6 C) may well indicate a peculiarly Roman process, be it metal working, wall painting or the consumption of contaminated food stuffs.

The unusual concentration of chromium in the multi-period occupation site in Church Field, Shapwick (see Figure 5.16) and the possible associations with chrome base wall painting is commented upon later (see page 236).

Perhaps most interesting time-related observation was the discovery of the medieval river erosion at the northern end of North Meadow Kirkdale (see page 175). If the

archaeological dating is correct, the river gravels and alluvium of half the field were eroded and replaced with new deposits somewhere between the Roman period and the 13th Century. At sometime during the 13th Century the whole meadow went under ridge and furrow which survives undisturbed (for the most part) to this day.
Considering that all of the fluvial deposits (whatever their date of deposition north *or* south of the buried palaeo-channel) were likely to have derived from a common source, the comparative paucity of measured soil elements (see Figures 5.1 O, 5.3 O, 5.4 O, & 5.6 O) in the replaced northern half would indicate an intensity of human activity in this locality sometime prior to the 13th Century and the relative lack of it since (except by boy scouts).
Again putting meat on the bone of identifying "time signatures" awaits the accumulation of more observational evidence.

5.4 TOWARDS A PRACTICABLE METHODOLOGY

The successful development of soil analysis as a practicable option for field archaeologists depends on it being robust, repeatable, economic on resources (materials and labour), timely in producing results, and reliable. At the moment it can succeed in some of these requirements but only at the expense of others. Accuracy and repeatability take time and economy on resources limit the potential benefits. But future prospects are good. This section discusses some of the practical aspects of the methodology as it was applied and the implication to future strategies.

5.4.1. Sampling and surveying

The sampling area and the size of the sampling grid was, in practice, determined by the soil storage facilities available and the throughput capacity of the laboratory (see further comments below). When looking at a dozen or so different sites, 100 samples per site were found to be manageable; a single site generating 1000 samples was onerous. At Hamm Farm (Kenn Moor), which covered a range of sampling scales, 1080 samples were taken and processing these took a considerable length of time. Assuming a laboratory capacity of **400 to 500 samples** per "run" the following sampling-grid sizes are suggested as practicable.

Table 5.10 Size of Surveys

Size of Survey	Area	Grid Size
Landscape	100 - 400 ha	50m – 100m
Field (s)	4 –16 ha	10m – 20m
Site	0.2 –1 ha	2m –5m
Feature	< 0.04 ha	< 1m

Sampling Problems: The number of samples taken is also limited by the time available and labour required in the field. Even with multiple-element analytical techniques, the drying and/or other soil preparation mandatory before analysis can take weeks, sometimes months, to complete. With the number of sites covered in this study some soil samples were in storage for a year before they got processed. In the field, and without assistance, sampling on any scale will require multiple visits, and the transport and storage of bulky soil samples bring their own difficulties. All these problems may well diminish as techniques and technology improve. With increased sensitivity, X-ray fluorescence spectrometers could eventually be suitable for archaeological use in the field. With the development of a GPS (Geographical Positioning Systems) based sampling protocols there would no longer be a need to lay out a sampling grid. Combine these with interpretive software and geo-chemical analysis would share the same availability as geophysical surveying.

Surveying Problems: An unwritten rule of mapping dictates that the area of most interest will occur at (and extend beyond) the edge of the map. In the case of site prospection (rather than a feature study), centring a grid on a surviving earthwork or geo-physically revealed features may not give the optimum result. The activity that left residues in the soil may have been in an area adjacent to or set apart from the surviving relic of buildings or ditches. The solution lies in covering an area that will more than encompass the suspected site, in essence to encompass the invisible "halo" of occupation. Quite simply this means the whole field and preferably at bit more. At Hardingworth, for example, the survey comprised of the whole field and portions of seven surrounding fields giving a zone of 6 ha, generating 360 samples (20m grid) in the middle of which sat the anticipated archaeology. Sampling a wider area also provides useful base data from the anthropogenically inactive (in a relative sense, at least) areas. There are also the usual practical field considerations in siting a grid; such

as using permanent features (gate posts, pylons, edges of buildings etc) to enable accurate recovery of the grid for later re-evaluations; aligning the grid on a north south orientation so that results are compatible with Ordnance Survey maps and magnetometry; and placing durable and easily visible hedge markers to ensure the accurate alignment of grids that cross field boundaries. GPS can be useful in all these circumstances provided a consistent accuracy in the order of ten to twenty centimetres can be guaranteed. The potential future developments described in the preceding paragraph would over come many of these problems.

Grid Size Problems, that is difficulties of interpretation that arise as the result of too much detail, of isolated high values and the risks in broad landscape surveys of entirely missing the detail have been discussed in Part 3 on page 114.

Survey Area Problems caused by macro features such as geology, soil series, agricultural practice etc. have also been considered above.

5.4.2 Soil Processing

The preparation of the soil for analysis (see Part 3, page 119) is perhaps the most time consuming component of the process. Air drying the soils and working them by hand to ensure they remain friable and ultimately sievable can, in the case of wet clays, take weeks if not months. Ideally samples should be taken in the summer months when the soils are relatively dry but before (again clay soils) they bake hard. Commercial soil analytical laboratories (e.g. those of ADAS[75]) oven dry soils and pass them through an automated grinding, sieving and mixing process. Access to such a system could significantly enhance the turnover time but, without a suitably low temperature setting, could compromise magnetic susceptibility evaluation.

5.4.3 Laboratory Analysis

Five separate laboratory analytical processes were used and are summarised in the following table (Table 5.10). The use of diverse assaying techniques assuages concerns about methodological bias.

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[75] Agricultural Development and Advisory Service ... a commercial government body linked to the Ministry of Agriculture, Fisheries & Food.

Table 5.11 Laboratory Analytical Processes

Analytical Process	Factors Evaluated	Preparation Required
Atomic Absorption Spectrometry	Lead, Copper, Zinc, Cadmium, Nickel, Cobalt, Chromium, & Manganese	Acid digests of oven dried soils
Spectrophotometry	Phosphorus	Acid digests of oven dried soils
Magnetic Susceptibility Metering	Magnetic Susceptibility	Air dried soils
High Temperature Treatment	Loss on Ignition	Air dried soils
pH Metering	pH	Air dried soils

The use of multiple factor analytical equipment such as ICP would indeed save time and would allow the consideration of other potentially indicative elements currently difficult to analyse by AAS. Whereas ICP can measure phosphorus concentrations the adoption of a single analytical process would risk losing the robustness of independent corroboration offered by applying an array of investigative methods.

5.4.4 Future Strategies

The methodology used in this piece of research was never state of the art, the equipment being used (e.g. single element AAS) imposing its own limitation on the scope and range of evaluation. This in its way forced an approach which may well have interpretive advantages. This is discussed more fully in the following section. Suffice it to say that had more "sophisticated" equipment been available it may have been used at the sacrifice of a diversity of approaches. Nevertheless, the metallic elements chosen for examination might usefully be expanded upon. It would have be instructive to have included the lighter metals (potassium & magnesium) as well as strontium and selenium all of which have shown evidence or at least indications of being useful indicators. Future strategies ought to include profile and depth sampling if only to confirm the adequacy or appropriateness of surface sampling. Finally, as has already been mentioned, a data base of anomaly investigations needs to be compiled if type signatures are to be identified.

Part Six: General Discussion of Recent Developments

When this research was initiated in 1997 (at first as part of a Master's Degree), very little comparable work on multi-element analysis of soils in the UK had been published[76]. More has been published during the preparation of this thesis. These include Entwistle & Abrahams (1997) and Entwistle *et al* (1998), who undertook work similar, in some ways, to that which is presented here; and research on soil lipids by Evershed *et al* (1997), Simpson *et al* (1998) and Bull *et al* (1998, 1999), which has some bearing, at least, on the adopted approach to archaeological soil analysis. A certain amount of recent or contemporary work on sites in other countries has proved particularly relevant and these include Bintliff *et al* (1990 &1992), Linderholm & Lundberg (1994) and Rimmington (1999).

Detailed discussion of the principles that underlie and the practicalities that surround the application of soil chemical analysis to archaeological investigations has been presented already in Parts 2 and 3 of this dissertation. In that presentation, a wide range of elements was considered and a detailed review of soil phosphorus included. It has been made clear (in the Introduction and in Part 2), however, that the main emphasis of this research was to be on the evaluation of heavy metals. It is intended that Part 6 be given over, for the most part, to a discussion of contemporary research on the presence of these metals in soils associated with past human settlements.

Early archaeological work on heavy-metal soil residues (Sokolof *et al*, 1952) is briefly reviewed in Part 2 (page 72). Some past and present key researchers are listed in Table 2.36 on page 75.

Davies *et al* (1988) and Bintliff *et al* (1990), from their joint researches into ancient sites in Greece, were the first to present clear evidence that, wherever ancient people worked or lived, concentrations of heavy metals in the soil were enhanced and that these residues persisted for many (hundreds if not thousands of) years. Using an atomic absorption spectrometer (similar to that used in this research), the authors concluded that the best candidate elements were copper, zinc and lead, whereas the evidence for nickel and manganese was less conclusive. They proposed that heavy metal accumulations could act "as markers of such occupation and complement evidence derived from other archaeological survey methods". They argued that archaeological

[76]The notable exception was Jane Entwistle's PhD thesis (1994).

sites could be better described as "halos" of human activity around the foci of occupation. Further, they argued, the application of heavy-metal soil surveys could reveal the intensity of past land-usage within a landscape. The present work largely agreed with these findings in that copper, lead and zinc (and cadmium) were found to be positive indicators of activity whilst nickel (with cobalt and chromium) and, to a large extent, manganese were negative indicators. These results were based on a wide selection of sites in the British Isles compared with the single farmstead (plus 4 or 5 associated transects) of Davies and Bintliff. In addition, sampling was a on a much more intense level than in previous work.

Several pieces of research on pre-historic settlements in Sweden and Finland (Miller *et al*, 1979; Arrhenius *et al*, 1981; and Asplund *et al*, 1989), carried out at roughly the same time as Davies' and Bintliff's surveys on mainland Greece, confirmed the importance of copper and, to some extent, zinc as site indicators.

In the early 1990s, Johan Linderholm and Erik Lundberg, both from the University of Umeå, Sweden, revisited a site first investigated almost forty years previously by Olaf Arrhenius (Arrhenius, 1955 – see also Part 2, page 96). Arrhenius had discovered conspicuous elevations of soil phosphorus associated with the foci of Late Bronze Age settlements in Östergötland, Sweden. Using the relatively new technique of inductively coupled plasma atomic emission spectrometry (ICP AES), Linderholm and Lundberg assessed soils from the site for heavy metals such as copper, lead, zinc, cobalt, chromium and manganese. Soil samples were taken from beneath the plough zone (which they assumed to be unsuitable because of agricultural disturbance) at points within and beyond the foci of human activity. Good correlations were found for many of the test elements, especially copper, zinc and (at certain locations) manganese. However, concentrations of lead proved too low for accurate detection and the background intensity of cobalt too high to allow any clear assessment. The authors concluded that these elements, lead and cobalt, were unsuitable indicators for past settlements, at least as far as analysis by ICP AES was concerned. Notwithstanding this, the poor association of cobalt (and chromium) with settlement sites was attributed to these metals not being of anthropogenic origin.

Contrary to the above findings, the work of Jane Entwistle (Entwistle, 1994, 1997, &1998) suggested a completely different suite of elements that could be associated with anthropogenic activities, whilst all the elements found by Davies *et al* (1988) and

Bintliff *et al* (1990) and those found in this study were relegated or dismissed. Entwistle examined top-soil samples from several ancient Hebridean *clachan* (rural settlements of medieval or possibly prehistoric origin) that were farmed (possibly continuously) until the mid 19th Century. Soil-metal content was analysed also using the (new at that time) multi-element atomic emission ICP spectroscopic procedure (ICP-AES). Although the technique allowed a wide ranging assessment, it was not without problems. The sensitivity of the machine prevented simultaneous measurements of the rarer elements with those of major abundance. It was also expensive to run and, although used for phosphorus evaluation, the author admitted subsequent laboratory analyses reverted to the photo-spectrometry and the "vanadomolybdate yellow" method (see Part 2, Box 2.3). In the event, the technique proved insufficiently sensitive to the levels of cadmium present (< 0.6 ppm) and showed poor accuracy for chromium. Nevertheless, a total of 33 elements were determined with acceptable precision. However, possibly because surrounding ("normal") soils were relatively rich in copper (70.3 ppm) and zinc (107 ppm), copper and zinc did not demonstrate any significant elevation in the soils from the settlement areas. Neither was there evidence of enrichment with lead (or nickel), so much so that Entwistle dismissed lead as a potential archaeological indicator. Among the metals tested for, a final short list of eight that significantly enriched the soils from the settlement areas (clachan) were presented. Namely, potassium (K), barium (Ba), lanthanum (La), cerium (Ce), praseodymium (Pr), caesium (Cs), thorium (Th) and rubidium (Rb). The occurrence of potassium in anthropogenic residues is well documented and barium is often associated with potassium in geo-chemical processes (Kabata-Pendias & Pendias, 1984). The next three metals on the list (La, Ce & Pr) are lanthanides and Entwistle speculated their presence derived from trace amounts that can occur in bone and teeth (but see comments by Rimmington below). Entwistle admitted that specific anthropogenic sources of rubidium and caesium were not known and that thorium was not an essential element in any organic process. This would not, of course, preclude its accumulation as a food chain contaminant. Away from the settlement focus, soil enrichments of two further elements, calcium and strontium, were attributed to the deliberate additions of shell-sand to cultivated fields as soil improvers.

In 1998 Rimmington completed a re-examination of Bintliff's Grecian top-soils (0-20cm) also using ICP-AE spectrometry (Rimmington, 1999). He was able to re-confirm the significance of zinc and (to a degree) lead as settlement indicators (but not copper) and, among the heavy metals, earmarked manganese as having potential. Rimmington

argued that "interference" from the high calcium content of the soil compromised lead assessment[77] and may have accounted for (what appeared to be) the high lanthanum content of the soils from one site (Note above Entwistle's explanation for the presence of lanthanides). The poor result for copper was attributed to "interference from modern agriculture". Of the other elements tested, Rimmington highlighted potassium and, particularly, barium as strong indicators, thus confirming, in part, Entwistle's findings. Cadmium again proved to be beyond the sensitivity of this technique (as it was applied). The author also noted the apparent "dilution" of certain heavy metals (nickel and chromium) in some settlement-soils which he attributed to the "divorcing" of geologically derived (and presumably non-anthropogenic) elements by accumulating organic material. The present thesis has examined the process of element enhancement and dilution. It has demonstrated the potential for element dilution through the competitive enrichment of soils with faeces, wood ash, etc.

The use of more-sophisticated spectroscopic techniques is always tempting as it affords analysis of a wider range of heavy metals. It would be disingenuous to say that if ICP AES had been available it would not have been used for this study. However, technical sophistication does not come without its cost. Inadequate standard materials, spectral interference and contaminations can, it has been shown, confound or obscure measurements. Simple element by element AAS, though time consuming, has proved reliable, accurate and sensitive. Cadmium, for example, has proved to be, in the soils tested, a useful and measurable indicator of human activity, but was below the range of detection by other workers.

The use of ICP AES has allowed the above researchers to include other elements and both Entwistle and Rimmington have identified potassium[78] and barium as settlement indicators. What was surprising was that both Lundberg and Entwistle were unable to demonstrate a positive response for lead. Whereas the latter dismisses lead as a contender, the former qualifies his comments. It has been commented (see page 36) that the potential for lead contamination was greater in the Romanised world and this indeed could be an explanation. The paucity of lead in northern Scotland and Sweden and its absence as a significant pollutant in the diets of people and their livestock may also be attributable to the geological availability of this metal.

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[77] Indeed several authorities argue that accurate lead assessment in calcium rich soils is difficult using high temperature spectroscopic techniques, such as ICP. Either the lead has to be extracted first or a cooler technique, such as AAS, be adopted (Martin, pers. com.).

[78] See also Part 2, Table 2.32 for other work on potassium as an anthropogenic biomarker.

The geology of the Hebrides is complex and largely of igneous origin. Entwistle's *clachans* are situated[79] within an area of intrusive (dykes and plutonic masses) and extrusive (lava fields) Tertiary basalts, although they actually lie on older and exposed Jurassic sediments which include sandstones, clays and limestones. During the Pleistocene the island was heavily glaciated and recent surface deposits include alluvial downwash from the weathered larva, blown calcareous sands and peat (Richey, 1961). Lindholm *et al* (1994) describe the underlying geology of Ostergotland as very ancient (Cambrian) sandstones and granite. The area was also heavily glaciated and surface soils are, for the most part, mineral-rich but unstructured clays. It is probable they also contain a significant loess component. For the most part, the soils examined in this thesis were lowland alluvial deposits overlying uncomplicated geology. Admittedly soils at two of the sites (Kinaleghin & Kirkdale) occur within an area that would have been directly[80] affected by the last glaciation, but none are, for example, impoverished upland soils or highly calcareous, factors which could effect the survival or reliable measurement of anthropogenic deposits. Davies *et al* (1988), Bintliff *et al* (1990) and Rimmington (1998) all dealt with the same calcareous soils (rendzinas) which overlay limestone in an area that was not subjected to the last glaciation. Such soils are largely derived from the local bedrock. Without many more data from different geological areas further speculation is pointless. However, it is must be evident that the interpretation of any soil analysis will have to take into account the pedogenesis of the soil.

The approach to this research has been largely taphonomic. The starting point has been a consideration of the activities which generate the anthropogenic deposits, followed by an examination of the soil processes by which some residues might survive. From this, potential indicators of past activities were proposed and finally these were tested for in the field. Although the identification of rarer elements, such as rubidium, caesium and thorium, as settlement indicators has been clearly shown (Entwistle, 1994), it is troubling when no clear biogenic pathway is obvious. Possibly, like lead, these are localised contaminants, but as no evaluations for these rare earths were made on the soils in this thesis, there is no room for further comment.

This dissertation and the research discussed above illustrates the usefulness of soil analysis for heavy metals in determining the foci of human settlements and the "halo" of activity surrounding them. As to the recognition of residues from more dispersed

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[79] 3.3 km north of Uig on the Trotternish Peninsular of northern Skye.
[80] Note: even the soils of southern England that were never covered by glaciers would have been indirectly affected by permafrost and wind borne loess.

deposits that derive, for example, from the manuring of outlying fields, the picture is less clear. However, other work, largely contemporary with this thesis, has proved very interesting.

Bethel *et al* (1994), examined soil samples from ancient and modern sewage sources and established that certain faecal lipids (5β-stanols), in particular coprostanol , survived as indicators of human activity (i.e. from the faeces of humans and domestic livestock) for hundreds of years and possibly for considerably longer (see Part 2, page 62). Evershed *et al* (1997) applied these findings to soil samples taken from transects across cultivated plots (either manured over a period of 13 years or not manured at all) at the Butser Ancient Farm site in Hampshire. The results indeed showed a significant increase in lipids in the manured areas, together with an elevation in magnetic susceptibility readings. However, phosphorus evaluations did not indicate any differences between the plots. Evershed *et al* argued that, in general, changes in soil chemistry as the result of manuring were short lived and that the measurement of specific elements, such as carbon, was unlikely to reveal an enhancement over time. However, they claimed that certain biological molecules (lipids), being among the slowly accumulating recalcitrant compounds, did have potential as *biomarkers*. This work was followed by studies (Bull *et al*, 1998) on the long term Rothamsted experimental plots (ongoing since 1852) where elevations in the soil of ruminant faecal lipids could still be recognised in land manured 120 years previously. Simpson *et al* (1998) examined possible fossil anthropogenic soils (Neolithic to Iron Age) of the Tofts Ness peninsula on Orkney. From the identification of lipids surviving in the soil, inputs of terrestrial vegetation and animal faecal material was inferred. The research into soil lipids as archaeological indicators of past manuring practices was reviewed by Bull *et al* (1999) who also reported promising developments on soil-persistent bile acids, amino acids and isotopes of carbon and nitrogen. As to the potential of heavy metal analysis in determining manured soils associated with rural settlements there is as yet too little information from which to draw any conclusion. However, unlike persistent organic molecules such as lipids, it is improbable that heavy metal information alone could identify specific (human, cow or pig faeces, etc) sources of manure.

The ways in which the work described in this thesis differs from other studies in this field are in the number of samples analysed, in the intensity of the sampling regime and in the treatment and presentation of the data. It is felt that a particular strength is the relatively wide range of sites examined (admittedly all in the British Isles) and the general agreement between sites which have pointed to lead, copper, zinc and cadmium

being positive indicators of settlement activity and nickel, cobalt and chromium being negative indicators whilst manganese remained, by and large, neutral.

At the conclusion of this research, taking full account of other contemporary studies, it is clear that a practical methodology for heavy metal soil analysis has been established. It is argued that future field surveys by archaeologists to establish the location of and analyse the activities within a site of past human activity cannot afford to ignore this technique.

Part Seven: General Conclusions

What archaeology might tell us about the past is determined by what relicts or other evidence happens to have survived above or below the surface. This evidence is what we are able to observe, to measure and to evaluate. Although the archaeological record may have an absolute limit, how much of it that is available to the archaeologist depends on the quality of the investigative techniques employed. It may be true that partial evidence will hinder interpretation, but there is no guarantee that a total knowledge of what survives of a past site or activity will render the interpretation any easier. However, it must be reasonable to assume that the more that can be extracted from the archaeological record the less likely a misinterpretation will be made.

Soil analysis provides another source of archaeological evidence. Previous work, over many years, has shown that the chemical composition of soil is altered by the activities of people. It has been argued in this thesis that, for ancient rural settlement sites at least, these changes are largely those resulting from the accumulation and relocation of domestic, agricultural (and sometimes industrial) waste. Because of the processes of surface relocation by plant and animal activity, measurements of the surviving residues of these deposits can be made within the top soil.

It has been shown that these residues, which include a range of heavy metals, phosphorus and organic carbon, together with physical measurements of the soil (such as pH and magnetic susceptibility), provide evidence of past human activity. It has been demonstrated that their evaluation allows the investigator to locate and to determine the extent of a settlement. Finally it has been shown that there is potential for such evaluations to afford insight into the nature of the past activities that took place. This research presents an effective investigative strategy that can and has been used successfully to identify sites of past human activity and to augment conventional techniques, most usefully in situations where the scope for applying conventional techniques is limited, i.e. sites lacking any surface evidence, be it earthworks, pottery scatters or other inorganic finds.

These results broadly meet the objectives set out at the beginning of this research. but there is much more to be done.

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APPENDIX I

Descriptive Statistics

1a. Descriptive Statistics of Shapwick "Church Field" 1996

Variable	N	N*	Mean	Median	TrMean	StDev
Mag.Sus.	258	0	31.77	26.00	30.08	16.63
LOI	258	0	11.655	11.346	11.549	1.668
Phosphorus	257	1	2112.7	1805.0	2033.5	905.1
Lead	258	0	35.996	34.422	34.942	7.952
Copper	258	0	42.004	42.218	42.018	3.442
Zinc	258	0	130.90	129.15	129.98	22.37
Cadmium	258	0	0.6761	0.6576	0.6594	0.2370
Nickel	258	0	39.716	40.321	39.757	4.817
Cobalt	255	3	15.563	15.453	15.472	3.094
Chromium	258	0	19.590	18.993	19.454	4.437
Manganese	258	0	844.5	811.7	833.5	278.1

Variable	SE Mean	Minimum	Maximum	Q1	Q3
Mag.Sus.	1.04	12.00	101.00	20.00	38.00
LOI	0.104	8.239	17.308	10.680	12.194
Phosphorus	56.5	596.6	5073.7	1509.2	2431.5
Lead	0.495	25.277	90.449	31.875	37.208
Copper	0.214	28.352	55.605	39.765	44.278
Zinc	1.39	89.07	200.38	114.06	145.79
Cadmium	0.0148	0.2966	2.8674	0.5389	0.7705
Nickel	0.300	25.397	52.015	36.493	42.835
Cobalt	0.194	9.149	24.333	13.229	17.548
Chromium	0.276	10.280	32.432	16.076	23.006
Manganese	17.3	258.0	1572.8	650.6	990.5

1b. Descriptive Statistics Shapwick "Church Field" 1998

Variable	N	N*	Mean	Median	TrMean	StDev
MS	746	0	43.373	39.000	42.379	18.361
LOI	746	0	13.675	13.570	13.679	1.753
pH	746	0	7.3480	7.4000	7.3540	0.1651
Phosphorus	746	0	2635.0	2537.2	2606.5	807.2
Lead	745	1	44.11	37.07	39.31	39.13
Copper	746	0	46.084	46.087	46.100	4.290
Zinc	746	0	175.52	176.51	175.55	24.50
Cadmium	746	0	0.74940	0.74414	0.74689	0.15820
Nickel	746	0	38.931	39.414	39.071	5.650
Cobalt	746	0	12.779	12.446	12.692	2.459
Chromium	746	0	34.443	32.760	34.026	5.555
Manganese	746	0	702.02	685.82	693.15	229.92

Variable	SE Mean	Minimum	Maximum	Q1	Q3
MS	0.672	10.000	104.000	29.000	55.000
LOI	0.064	5.338	19.112	12.399	15.045
pH	0.0060	6.6000	7.8000	7.3000	7.5000
Phosphorus	29.6	245.1	7359.8	2079.3	3137.4
Lead	1.43	23.49	530.37	34.38	43.38
Copper	0.157	32.609	75.151	43.687	48.797
Zinc	0.90	103.33	284.00	158.58	193.57
Cadmium	0.00579	0.35890	1.32121	0.64200	0.86186
Nickel	0.207	9.000	65.057	36.111	42.247
Cobalt	0.090	6.765	24.121	11.299	14.226
Chromium	0.203	20.420	65.268	30.592	36.832
Manganese	8.42	86.22	1940.70	574.11	811.25

2. Descriptive Statistics Shapwick "Henry"

Variable	N	N*	Mean	Median	TrMean	StDev
MS	152	2	25.053	23.000	24.603	8.735
LOI	105	49	11.992	11.822	11.879	3.220
Phosphor	106	48	1460.6	1418.3	1444.6	339.8
Lead	106	48	47.12	43.85	45.59	13.27
Copper	106	48	52.006	50.025	51.585	8.309
Zinc	106	48	118.88	114.25	117.47	26.37
Cadmium	106	48	1.0741	1.0500	1.0594	0.2617
Nickel	106	48	46.799	46.575	46.558	8.091
Cobalt	106	48	16.155	16.125	16.134	2.899
Chromium	106	48	23.024	21.000	22.578	6.099
Manganes	106	48	988.5	932.5	985.8	252.6

Variable	SE Mean	Minimum	Maximum	Q1	Q3
MS	0.709	10.000	55.000	20.000	30.000
LOI	0.314	6.272	21.809	9.532	14.069
Phosphor	33.0	836.5	2689.9	1232.6	1672.5
Lead	1.29	32.00	129.60	39.85	49.06
Copper	0.807	38.000	75.000	46.175	56.963
Zinc	2.56	73.00	227.00	102.00	130.50
Cadmium	0.0254	0.7000	1.9000	0.8500	1.2000
Nickel	0.786	29.600	70.850	40.600	52.112
Cobalt	0.282	9.875	23.575	14.200	18.150
Chromium	0.592	15.500	42.000	18.500	26.625
Manganes	24.5	425.0	1739.5	806.7	1166.6

3. Descriptive Statistics Shapwick "Sladwick"

Variable	N	N*	Mean	Median	TrMean	StDev
MS	119	0	12.580	12.000	12.262	3.988
LOI	119	0	14.743	14.889	14.829	1.942
Phosphor	110	9	2298.1	2000.8	2184.8	996.0
Lead	119	0	42.30	40.35	40.69	13.35
Copper	118	1	45.322	44.712	45.047	4.166
Zinc	119	0	150.00	150.67	149.26	20.82
Cadmium	119	0	0.6591	0.6338	0.6512	0.1588
Nickel	119	0	40.279	39.926	40.110	4.012
Cobalt	104	15	21.471	19.729	21.072	7.297
Chromium	119	0	31.737	31.405	31.747	6.224
Manganes	119	0	494.4	409.7	469.6	245.4

Variable	SE Mean	Minimum	Maximum	Q1	Q3
MS	0.366	6.000	37.000	10.000	14.000
LOI	0.178	8.326	19.132	13.541	16.001
Phosphor	95.0	941.0	6707.3	1675.9	2613.9
Lead	1.22	24.19	157.08	37.46	42.94
Copper	0.384	34.797	65.839	42.553	46.951
Zinc	1.91	99.93	261.74	138.17	160.17
Cadmium	0.0146	0.3550	1.1879	0.5484	0.7636
Nickel	0.368	31.241	51.861	37.710	42.600
Cobalt	0.716	10.496	42.733	15.965	26.072
Chromium	0.571	15.308	44.688	27.453	36.039
Manganes	22.5	161.1	1405.6	344.6	555.2

4a. Descriptive Statistics Hamm Farm (aka Kenn Moor) 50 Metre Grid

Variable	N	N*	Mean	Median	TrMean	StDev
MS	228	0	13.838	13.000	13.621	4.676
pH	228	0	6.3513	6.3000	6.3699	0.7267
LOI	227	1	11.016	9.477	10.641	4.767
Phosphor	227	1	1356.6	1245.5	1317.4	527.0
Lead	226	2	43.928	40.576	42.925	12.088
Copper	227	1	22.154	21.192	21.811	8.159
Zinc	227	1	188.65	180.80	185.37	44.44
Cadmium	227	1	0.6070	0.5316	0.5743	0.3341
Nickel	227	1	21.808	22.723	21.902	4.401
Cobalt	226	2	9.168	9.039	9.178	1.728
Chromium	227	1	26.143	26.002	26.225	6.644
Manganes	227	1	577.5	483.1	549.8	288.4

Variable	SE Mean	Minimum	Maximum	Q1	Q3
MS	0.310	7.000	27.000	10.000	17.000
pH	0.0481	4.6000	7.6000	5.8000	7.0000
LOI	0.316	4.739	35.190	7.354	13.546
Phosphor	35.0	511.1	5356.9	965.8	1648.0
Lead	0.804	23.258	97.643	35.897	48.750
Copper	0.542	9.140	49.442	15.140	27.436
Zinc	2.95	96.32	477.53	160.38	208.95
Cadmium	0.0222	0.0519	2.7152	0.3925	0.7094
Nickel	0.292	10.398	32.763	18.705	24.918
Cobalt	0.115	4.619	13.060	8.035	10.444
Chromium	0.441	11.384	39.630	20.699	31.954
Manganes	19.1	221.1	1779.9	391.6	689.1

4b. Descriptive Statistics Hamm Farm (aka Kenn Moor) 20 Metre Grid North

Variable	N	N*	Mean	Median	TrMean	StDev
MS	241	1	16.809	14.000	15.493	11.451
pH	242	0	0.16441	0.16808	0.16376	0.02524
LOI	242	0	12.134	12.090	12.080	2.632
Phosphor	242	0	1288.3	1239.4	1275.0	296.7
Lead	242	0	42.430	41.844	42.078	6.866
Copper	242	0	15.222	14.267	14.771	4.471
Zinc	242	0	178.42	177.91	177.62	20.27
Cadmium	241	1	0.4885	0.4468	0.4726	0.2002
Nickel	242	0	24.813	24.692	24.811	2.813
Cobalt	242	0	9.1234	9.0209	9.0581	1.2793
Chromium	242	0	32.710	32.680	32.716	3.402
Manganes	242	0	429.85	436.38	425.26	100.89

Variable	SE Mean	Minimum	Maximum	Q1	Q3
MS	0.738	8.000	149.000	12.000	19.000
pH	0.00162	0.12821	0.21739	0.13841	0.18519
LOI	0.169	6.461	19.430	9.991	13.967
Phosphor	19.1	614.9	2164.9	1092.0	1449.8
Lead	0.441	27.856	85.933	38.144	45.506
Copper	0.287	8.922	36.676	12.351	16.481
Zinc	1.30	128.39	265.44	164.54	188.24
Cadmium	0.0129	0.1065	1.7727	0.3697	0.5778
Nickel	0.181	17.434	34.614	22.814	26.933
Cobalt	0.0822	6.5854	14.0271	8.2499	9.8167
Chromium	0.219	24.767	42.265	30.155	35.393
Manganes	6.49	233.36	901.36	351.92	492.03

4c. Descriptive Statistics Hamm Farm (aka Kenn Moor) 20 Metre Grid South

Variable	N	N*	Mean	Median	TrMean	StDev
MS	247	0	14.514	11.000	13.498	8.205
pH	247	0	0.17739	0.18182	0.17768	0.02311
LOI	246	1	14.900	15.664	14.938	4.979
Phosphor	245	2	1591.2	1589.2	1564.6	561.7
Lead	246	1	53.15	52.98	52.03	16.30
Copper	245	2	18.826	18.694	18.577	4.385
Zinc	247	0	204.83	210.32	205.55	38.97
Cadmium	247	0	0.7289	0.7267	0.7195	0.2575
Nickel	247	0	21.757	22.807	21.905	3.857
Cobalt	247	0	7.7701	7.8728	7.7735	1.1689
Chromium	247	0	25.857	25.960	25.812	3.970
Manganes	247	0	407.08	378.89	399.35	118.49

Variable	SE Mean	Minimum	Maximum	Q1	Q3
MS	0.522	7.000	65.000	10.000	16.000
pH	0.00147	0.10309	0.23256	0.16129	0.19608
LOI	0.317	4.929	25.874	11.606	18.246
Phosphor	35.9	429.6	4173.0	1255.1	1869.5
Lead	1.04	24.99	131.29	39.33	61.88
Copper	0.280	10.724	44.361	15.740	21.130
Zinc	2.48	113.47	319.03	179.81	232.87
Cadmium	0.0164	0.1924	1.5620	0.5309	0.9061
Nickel	0.245	12.096	30.144	19.111	24.655
Cobalt	0.0744	4.2109	11.1440	6.9659	8.5856
Chromium	0.253	17.221	35.566	22.729	28.495
Manganes	7.54	216.65	908.14	321.48	480.75

4d. Descriptive Statistics Hamm Farm(aka Kenn Moor) 10 Metre Grid One

Variable	N	Mean	Median	TrMean	StDev	SE Mean
MS	125	13.048	12.000	12.673	3.372	0.302
pH	125	0.17715	0.17857	0.17761	0.01653	0.00148
LOI	125	14.539	14.772	14.516	2.249	0.201
Phosphor	125	1408.5	1397.1	1385.1	399.5	35.7
Lead	125	45.032	45.137	44.922	5.188	0.464
Copper	125	13.390	13.185	13.283	2.826	0.253
Zinc	125	187.03	184.07	186.38	22.29	1.99
Cadmium	125	0.6317	0.6345	0.6254	0.2241	0.0200
Nickel	125	24.068	23.649	23.975	2.436	0.218
Cobalt	125	8.4189	8.2808	8.3849	0.7849	0.0702
Chromium	125	31.789	31.061	31.668	3.320	0.297
Manganes	125	388.90	367.04	378.81	92.44	8.27

Variable	Minimum	Maximum	Q1	Q3
MS	8.000	35.000	11.000	14.000
pH	0.13333	0.21739	0.16949	0.18693
LOI	10.157	19.998	12.516	16.060
Phosphor	582.7	3307.6	1068.2	1646.9
Lead	33.214	61.319	41.420	48.040
Copper	8.771	24.086	11.058	15.318
Zinc	135.95	248.05	167.58	203.26
Cadmium	0.2002	1.1697	0.4381	0.7883
Nickel	12.962	32.665	22.869	25.193
Cobalt	6.8145	11.1341	7.8775	8.7579
Chromium	23.314	42.265	29.818	33.282

4e. **Descriptive Statistics Hamm Farm (aka Kenn Moor) 10 Metre Grid Two**

Variable	N	N*	Mean	Median	TrMean	StDev
MS	119	2	12.244	12.000	12.178	1.882
pH	121	0	0.18744	0.18868	0.18829	0.01580
LOI	120	1	12.999	12.895	12.977	1.629
Phosphor	120	1	1182.0	1190.5	1181.3	181.1
Lead	121	0	46.69	44.49	44.82	22.54
Copper	121	0	16.219	14.356	15.778	4.759
Zinc	120	1	171.03	171.09	171.14	13.18
Cadmium	121	0	0.3689	0.3753	0.3694	0.1178
Nickel	121	0	22.126	21.916	22.081	2.430
Cobalt	121	0	8.2030	8.0497	8.1171	1.0977
Chromium	121	0	32.513	32.226	32.444	2.627
Manganes	121	0	359.53	341.02	351.15	96.58

Variable	SE Mean	Minimum	Maximum	Q1	Q3
MS	0.173	7.000	18.000	11.000	13.000
pH	0.00144	0.13889	0.21739	0.17857	0.19608
LOI	0.149	9.439	18.119	12.092	14.113
Phosphor	16.5	683.3	1629.7	1051.2	1311.6
Lead	2.05	29.06	285.25	41.78	46.84
Copper	0.433	9.984	33.945	13.121	17.561
Zinc	1.20	132.80	206.49	163.04	179.72
Cadmium	0.0107	0.0984	0.6539	0.3014	0.4350
Nickel	0.221	15.514	28.418	20.685	23.219
Cobalt	0.0998	6.5057	13.3225	7.4547	8.6881
Chromium	0.239	27.068	42.264	30.651	34.278
Manganes	8.78	106.64	901.36	304.06	391.74

4f. **Descriptive Statistics Hamm Farm (aka Kenn Moor) 10 Metre Grid Three**

Variable	N	N*	Mean	Median	TrMean	StDev
MS	127	0	16.630	17.000	16.391	4.404
pH	126	1	0.15554	0.14085	0.15409	0.02664
LOI	125	2	11.056	10.488	10.976	1.878
Phosphor	126	1	1322.5	1345.7	1320.4	242.1
Lead	127	0	49.12	46.30	46.38	22.74
Copper	127	0	16.771	16.545	16.621	3.376
Zinc	127	0	178.92	179.93	178.92	14.59
Cadmium	127	0	0.4307	0.4279	0.4291	0.1246
Nickel	127	0	26.281	26.562	26.357	2.596
Cobalt	127	0	9.792	9.802	9.715	1.473
Chromium	127	0	35.209	35.313	35.213	2.361
Manganes	127	0	457.47	469.76	456.70	94.13

Variable	SE Mean	Minimum	Maximum	Q1	Q3
MS	0.391	9.000	49.000	14.000	19.000
pH	0.00237	0.12821	0.21277	0.13333	0.18182
LOI	0.168	8.174	15.859	9.672	12.378
Phosphor	21.6	709.0	2186.6	1155.2	1464.3
Lead	2.02	38.24	290.00	43.72	48.55
Copper	0.300	9.526	33.945	14.900	18.507
Zinc	1.29	132.50	230.14	171.50	185.00
Cadmium	0.0111	0.1076	0.9349	0.3686	0.5041
Nickel	0.230	18.091	31.697	24.956	27.981
Cobalt	0.131	7.318	13.838	8.746	10.334
Chromium	0.209	28.173	42.402	33.802	36.709
Manganes	8.35	182.70	953.61	395.23	516.63

4g. **Descriptive Statistics Hamm Farm (aka Kenn Moor) 10 Metre Grid Four**

Variable	N	N*	Mean	Median	TrMean	StDev
MS	117	0	11.496	11.000	10.914	4.421
LOI	117	0	19.593	19.797	19.606	2.595
pH	117	0	5.1684	5.1000	5.1400	0.3960
Phosphor	117	0	2011.2	1908.5	1973.2	462.1
Lead	117	0	61.276	60.783	60.821	8.740
Copper	117	0	19.953	19.353	19.489	4.906
Cadmium	117	0	0.9322	0.9066	0.9175	0.2256
Zinc	117	0	232.84	232.73	232.32	23.48
Nickel	116	1	24.216	24.000	24.298	2.663
Cobalt	117	0	8.3512	8.5139	8.3755	0.8458
Chromium	117	0	26.678	26.617	26.835	2.605
Manganes	117	0	362.35	350.52	359.90	68.02

Variable	SE Mean	Minimum	Maximum	Q1	Q3
MS	0.409	1.000	48.000	10.000	12.000
LOI	0.240	11.548	27.284	17.883	21.214
pH	0.0366	4.5000	6.3000	4.9000	5.4000
Phosphor	42.7	1148.4	4463.1	1759.8	2161.3
Lead	0.808	43.303	115.215	56.368	65.337
Copper	0.454	12.699	44.361	17.013	21.833
Cadmium	0.0209	0.4891	1.9964	0.7668	1.0561
Zinc	2.17	168.50	351.48	217.85	243.65
Nickel	0.247	13.000	34.000	23.000	26.000
Cobalt	0.0782	5.8121	9.9457	7.8161	8.9273
Chromium	0.241	17.116	31.162	25.438	28.367
Manganes	6.29	208.11	621.28	315.48	407.25

5. **Descriptive Statistics Puxton**

Variable	N	Mean	Median	TrMean	StDev	SE Mean
MS	278	10.608	10.000	10.336	2.812	0.169
LOI	278	10.011	9.975	9.991	1.298	0.078
Phosphor	278	1190.8	1118.3	1157.2	457.6	27.4
Lead	278	52.33	47.85	49.84	16.84	1.01
Copper	278	16.801	16.700	16.759	2.432	0.146
Zinc	278	139.17	137.25	138.06	19.38	1.16
Cadmium	278	0.13038	0.10000	0.12090	0.13225	0.00793
Nickel	278	26.946	27.025	26.930	2.717	0.163
Cobalt	278	11.894	11.750	11.836	1.777	0.107
Chromium	278	29.687	29.600	29.704	3.439	0.206
Manganes	278	809.3	820.2	803.4	209.2	12.5

Variable	Minimum	Maximum	Q1	Q3
MS	6.000	30.000	9.000	11.000
LOI	6.543	14.992	9.135	10.865
Phosphor	410.1	2913.5	837.8	1419.5
Lead	31.95	153.95	43.59	54.36
Copper	10.300	25.550	15.100	18.363
Zinc	98.00	297.50	127.50	148.50
Cadmium	0.00000	0.50000	0.00800	0.21250
Nickel	20.550	34.350	24.900	28.775
Cobalt	8.250	17.300	10.637	12.962
Chromium	20.000	40.600	27.600	32.100
Manganes	273.0	1507.5	648.5	927.0

6. **Descriptive Statistics Vole**

Variable	N	Mean	Median	TrMean	StDev	SE Mean
MS	105	12.086	10.000	10.989	8.106	0.791
pH	105	6.5562	6.4000	6.5526	0.7335	0.0716
LOI	105	17.457	17.417	17.379	3.896	0.380
Phosphor	105	1969.6	1812.1	1900.8	658.1	64.2
Lead	105	35.599	35.157	34.791	8.994	0.878
Copper	105	19.584	17.498	18.557	7.884	0.769
Zinc	105	165.6	148.9	151.8	107.7	10.5
Cadmium	105	0.1953	0.1933	0.1903	0.1185	0.0116
Nickel	105	26.760	26.501	26.640	2.585	0.252
Cobalt	105	12.070	12.034	12.030	1.160	0.113
Chromium	105	24.634	24.973	24.609	2.917	0.285
Manganes	105	511.2	512.4	507.7	135.2	13.2

Variable	Minimum	Maximum	Q1	Q3
MS	8.000	83.000	9.500	12.000
pH	5.2000	7.9000	6.0000	7.2000
LOI	9.011	44.109	16.331	18.994
Phosphor	1236.4	5195.1	1519.0	2218.4
Lead	22.413	106.053	32.580	36.860
Copper	11.510	78.868	16.063	20.157
Zinc	107.1	1178.9	140.9	162.6
Cadmium	0.0000	0.6664	0.1070	0.2626
Nickel	20.460	43.811	25.279	28.088
Cobalt	8.907	18.488	11.342	12.678
Chromium	17.967	33.040	22.338	26.708
Manganes	262.8	1000.0	415.4	589.5

7. **Descriptive Statistics Hardingworth**

Variable	N	N*	Mean	Median	TrMean	StDev
MS	334	4	12.413	11.000	11.220	7.704
pH	338	0	5.7879	5.6000	5.7326	0.5549
LOI	338	0	14.339	14.148	14.294	2.599
Phosphor	334	4	2726.1	2631.5	2688.2	656.1
Lead	334	4	50.16	46.55	47.19	23.91
Copper	334	4	14.043	13.781	13.887	2.699
Zinc	334	4	187.91	167.64	179.29	62.60
Cadmium	334	4	0.5778	0.5606	0.5724	0.2108
Nickel	334	4	26.414	26.147	26.340	2.140
Cobalt	334	4	11.274	11.088	11.225	1.265
Chromium	334	4	37.552	37.441	37.434	4.925
Manganes	334	4	450.97	429.30	440.29	122.56

Variable	SE Mean	Minimum	Maximum	Q1	Q3
MS	0.422	6.000	76.000	9.000	13.000
pH	0.0302	4.8000	7.7000	5.4000	5.9000
LOI	0.141	6.905	28.008	12.756	15.858
Phosphor	35.9	1282.9	5295.2	2241.0	3086.9
Lead	1.31	35.36	344.51	43.25	50.52
Copper	0.148	8.483	29.403	12.532	15.319
Zinc	3.43	112.44	557.94	153.12	194.38
Cadmium	0.0115	0.0457	1.3059	0.4539	0.6831
Nickel	0.117	19.469	35.079	24.919	27.652
Cobalt	0.069	6.355	17.079	10.496	11.948
Chromium	0.269	23.285	70.378	34.436	40.313
Manganes	6.71	246.39	1130.60	370.64	502.21

8. Descriptive Statistics Lower Woods

Variable	N	Mean	Median	TrMean	StDev	SE Mean
MS	91	25.85	22.00	24.27	14.95	1.57
LOI	91	21.393	21.795	21.735	3.590	0.376
Phosphor	91	3018	2936	2995	1189	125
Lead	91	76.57	71.66	74.99	21.80	2.28
Copper	91	32.911	32.606	33.105	5.179	0.543
Zinc	91	189.71	181.50	186.11	33.13	3.47
Cadmium	91	1.0780	1.1183	1.0734	0.3066	0.0321
Nickel	91	30.210	30.559	30.390	3.318	0.348
Chromium	91	22.173	22.567	22.283	4.621	0.484
Manganes	91	774.1	816.7	775.9	271.6	28.5

Variable	Minimum	Maximum	Q1	Q3
MS	6.00	81.00	17.00	26.00
LOI	5.932	27.847	19.943	23.755
Phosphor	159	6214	2161	3699
Lead	13.64	172.69	64.91	83.82
Copper	9.419	44.853	30.979	34.577
Zinc	141.00	313.85	167.91	197.53
Cadmium	0.3697	2.1450	0.9219	1.2275
Nickel	17.792	37.786	28.519	32.125
Chromium	4.536	37.543	19.192	24.863
Manganes	263.0	1264.7	560.1	977.3

9. Descriptive Statistics Blackcliff Wood

Variable	N	N*	Mean	Median	TrMean	StDev
MS	79	0	39.43	31.00	32.18	44.69
pH	78	1	6.1769	6.1500	6.1914	0.6060
LOI	79	0	16.396	14.263	15.523	6.623
Phosphor	79	0	1832	1546	1703	900
Lead	79	0	61.19	55.79	58.58	18.35
Copper	79	0	9.868	9.339	9.643	2.579
Zinc	79	0	132.81	124.01	127.67	39.25
Cadmium	79	0	0.9495	0.8410	0.9021	0.4318
Nickel	79	0	22.432	22.614	22.496	3.549
Cobalt	79	0	8.957	8.989	8.953	1.486
Chromium	79	0	28.114	27.991	28.093	4.144
Manganes	79	0	800.6	786.4	797.8	162.9

Variable	SE Mean	Minimum	Maximum	Q1	Q3
MS	5.03	21.00	390.00	26.00	37.00
pH	0.0686	4.5000	7.5000	5.7750	6.6000
LOI	0.745	8.198	48.197	12.685	18.028
Phosphor	101	836	5729	1352	2072
Lead	2.06	41.39	141.49	51.41	64.71
Copper	0.290	5.472	20.873	8.333	11.148
Zinc	4.42	88.36	338.19	111.38	144.77
Cadmium	0.0486	0.2527	3.0127	0.6599	1.0628
Nickel	0.399	12.741	30.132	20.455	24.778
Cobalt	0.167	5.003	13.071	7.874	9.778
Chromium	0.466	19.341	39.514	25.311	30.761
Manganes	18.3	288.9	1310.2	703.6	896.8

10. **Descriptive Statistics Kirkdale South Meadow**

Variable	N	Mean	Median	TrMean	StDev	SE Mean
MS	111	30.378	30.000	29.949	10.455	0.992
pH	111	4.7523	4.6000	4.6778	0.5951	0.0565
LOI	111	8.849	8.790	8.701	1.476	0.140
Phosphor	111	1810.7	1794.3	1799.0	493.5	46.8
Lead	111	80.19	70.03	75.82	37.92	3.60
Copper	111	15.766	14.480	14.974	5.395	0.512
Zinc	111	99.76	97.88	97.96	25.41	2.41
Cadmium	111	0.2054	0.2001	0.1936	0.1598	0.0152
Nickel	111	15.667	15.648	15.635	2.761	0.262
Cobalt	111	11.225	10.589	11.107	2.173	0.206
Chromium	111	13.153	13.055	13.085	1.554	0.148
Manganes	111	702.8	691.5	702.6	166.4	15.8

Variable	Minimum	Maximum	Q1	Q3
MS	10.000	65.000	23.000	36.000
pH	4.0000	7.2000	4.4000	4.8000
LOI	6.417	15.526	7.944	9.313
Phosphor	806.9	3329.3	1420.6	2154.3
Lead	32.49	213.02	54.05	91.95
Copper	8.387	43.888	12.908	16.983
Zinc	49.90	309.15	88.64	108.46
Cadmium	0.0000	0.6745	0.0922	0.3025
Nickel	10.127	24.203	13.764	17.520
Cobalt	7.469	17.442	9.625	12.102
Chromium	9.426	19.953	12.234	13.888
Manganes	332.7	1090.8	599.6	843.2

11. **Descriptive Statistics Kirkdale North Meadow**

Variable	N	N*	Mean	Median	TrMean	StDev
MS	117	2	21.504	19.000	20.829	9.538
pH	118	1	6.3203	6.3000	6.3170	0.5492
LOI	119	0	10.690	10.638	10.647	1.312
Phosphor	119	0	1444.2	1343.2	1402.5	493.0
Lead	119	0	54.55	48.52	53.36	20.57
Copper	119	0	15.613	15.232	15.305	4.036
Zinc	119	0	121.89	123.13	121.41	16.62
Cadmium	119	0	0.1864	0.1889	0.1801	0.1186
Nickel	119	0	22.765	22.015	22.470	4.073
Cobalt	119	0	18.832	18.923	18.777	3.246
Chromium	119	0	13.210	12.791	13.016	2.627
Manganes	119	0	921.4	998.3	922.4	232.9

Variable	SE Mean	Minimum	Maximum	Q1	Q3
MS	0.882	7.000	59.000	14.000	28.000
pH	0.0506	5.3000	7.5000	5.8000	6.8000
LOI	0.120	8.227	14.525	9.744	11.520
Phosphor	45.2	443.0	3486.8	1136.8	1645.3
Lead	1.89	26.91	111.92	38.23	65.92
Copper	0.370	8.551	49.116	13.570	16.721
Zinc	1.52	79.93	188.38	111.11	130.54
Cadmium	0.0109	0.0000	0.7330	0.1030	0.2565
Nickel	0.373	14.835	36.750	20.475	23.910
Cobalt	0.298	12.250	27.417	16.171	21.066
Chromium	0.241	9.240	22.626	11.368	14.700
Manganes	21.4	406.9	1439.7	670.3	1095.1

12. **Descriptive Statistics Kinaleghin**

Variable	N	N*	Mean	Median	TrMean	StDev
MS	93	2	25.54	18.00	22.61	20.32
pH	94	1	5.7223	5.6000	5.6821	0.5135
Loss on	95	0	10.630	9.973	10.349	3.206
Phosphor	95	0	2620	2351	2480	1194
Lead	95	0	31.424	29.592	30.267	8.376
Copper	95	0	28.121	26.965	27.589	8.257
Zinc	95	0	98.29	88.12	92.38	37.37
Cadmium	95	0	0.2317	0.2184	0.2262	0.1228
Nickel	95	0	26.304	25.902	26.089	2.947
Cobalt	95	0	8.025	8.065	8.031	1.028
Chromium	95	0	14.271	13.993	14.154	1.725
Manganes	95	0	775.8	785.8	777.2	123.6

Variable	SE Mean	Minimum	Maximum	Q1	Q3
MS	2.11	9.00	139.00	14.50	27.50
pH	0.0530	4.9000	7.4000	5.4000	6.0000
Loss on	0.329	5.697	34.588	9.128	11.247
Phosphor	122	822	7835	1873	2950
Lead	0.859	24.139	97.625	27.921	31.848
Copper	0.847	14.057	65.748	22.665	33.686
Zinc	3.83	70.43	362.51	82.10	100.02
Cadmium	0.0126	0.0475	0.6017	0.1410	0.3227
Nickel	0.302	21.369	38.607	24.231	27.717
Cobalt	0.105	5.477	10.201	7.265	8.676
Chromium	0.177	10.882	20.015	13.086	14.988
Manganes	12.7	435.9	1081.5	696.3	847.8

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